DEVELOPMENT OF EDUCATIONAL MODELS FOR TRAINING ON CRYOGENICS AND VACUUM TECHNOLOGY

A project report submitted in partial fulfillment of the requirements for the degree of

Bachelor of Technology

In

Mechanical Engineering

By:

Devendra Nenava

Sourabh Singh Raghuvanshi

National Institute of Technology Rourkela

Rourkela-769008, Orissa

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Under the guidance of

PROF. S. K. Sarangi

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CERTIFICATE

This is to certify that the Project entitled "**STUDY OF DIGITAL MODULATION TECHNIQUES IN THE PRESENCE AND ABSENCE OF NOISE**" submitted by **Sri Sourabh Singh Raghuvanshi** has in partial fulfillment of the requirements for the award of **Bachelor of Technology Degree** in **Mechanical Engineering** at **National Institute of Technology, Rourkela** (Deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other university/Institute for the award of any Degree or Diploma.

Place: NIT Rourkela

Date:

(Prof. S.K. Sarangi)
Department of Mechanical Engineering
NIT Rourkela

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CONTENTS

ABSTRACT

This project deals with study, design and construction of laboratory apparatus in Cryogenics Engineering and Vacuum Technology field. Project's aim is to develop such laboratory apparatus and model which can serve as the laboratory experiments for both undergraduate and post graduate students. This project work is broadly classified into two sub projects:--

1. Design & Construction of Cryogenic Apparatus
2. Design & Construction of various apparatus related to Vacuum Technology

In the cryogenic field, we are developing an apparatus which will use liquid nitrogen as the working fluid and will demonstrate various accessories of a basic cryogenic setup such as storage Dewars, insulated pipelines, valves etc. Also heat in leak measurement will be done with the help of two temperature measuring devices across a test pipeline. Level of vacuum is made variable by connecting it to a rotary pump through a buffer vessel. Design of various components is done like thickness and length of test pipeline , capacity of vaporizer, safety devices, calculations of heat transfer coefficients and inner & outer wall temperatures through a programmed iterative process is done. At last predicted nature of heat in leak variation with change in vacuum level is discussed and complete bill of materials is given.

For Vacuum Technology lab, design and construction of various apparatus for conducting experiments related to vacuum science was to be done. Two apparatus, one for pumping speed measurement by constant volume method and other related to boiling point of water at room temperature ad reduced pressure, sound propagation n vacuum and forces in vacuum is designed and constructed. Also, experimental readings, tables & graphs for these experiments are documented so that they can be used as standard results.

Apart from these, a vacuum apparatus for measurement of pumping speed by constant pressure method is designed and constructed by us in Vacuum Lab, IIT Kharagpur and results obtained are compared with that of constant pressure method. Bill of materials for setting this apparatus in our institute is given.

Design of an apparatus for measurement of conductance of vacuum pipes & that of overall conductance of a number of pipes of different diameters in parallel is completed. Bill of materials for the same is suggested.

Designing of new vacuum vessels to be purchased for Vacuum & Cryogenics Lab, NIT Rourkela is also done using Roark’s formulas for stress and strain. Vessel design supported with calculations and number of figures is also given.

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Chapter 1

LIST OF APPARATUS CONSTRUCTED , EXPERIMENTS DONE & BILL OF MATERIALS FOR PROPOSED APPARATUS

LIST OF APPARATUS CONSTRUCTED , EXPERIMENTS DONE & BILL OF MATERIALS FOR PROPOSED APPARATUS –

1) Pumping speed measurement by constant pressure method.

2) Pumping speed measurement by constant volume method.

3) Boiling of water at room temperature & reduction in the intensity of sound with variation in vacuum level.

4) Conductance measurement in a vacuum piping (parallel) set-up.

5) Design of new vacuum vessels to be purchased.

6) Design of cryogenic apparatus for measurement of heat leak across a variable vacuum test pipeline & demonstration of various cryogenic accessories.

PUMPING SPEED MEASUREMENT BY CONSTANT PRESSURE METHOD

*Apparatus constructed in vacuum laboratory of I.I.T(INDIAN INSTITUTE OF TECHNOLOGY) KHARAGPUR.

*Experiment conducted &results obtained.

*Bill of materials is completed & apparatus is proposed to be set here in N.I.T (NATIONAL INSTITUTE OF TECHNOLOGY) ROURKELA.)

Bill of materials:

S.NO.	**COMPONENTS**	**QUANTITY & SPECIFICATION**
1.	Vessel	25 l(1)
2.	Rotary-pump	250l/min(1)
3.	Needle-valve	(1)
4.	Ball -valve/shut-off valve	(1)
5.	Beaker	(1) 1000ml capacity
6.	Burette with a stand	(1)
7.	Rotary pump oil	1 L
8.	Rubber tubing	(1)
9.	T-Connection	(1)
10.	Connectors & Reducer	-

Table 1.1 bill of materials for pumping speed measurement by constant pressure method

PUMPING SPEED MEASUREMENT BY CONSTANT VOLUME METHOD (ROTARY PUMP)

*Apparatus constructed

*Experiment conducted & results obtained

Components of the apparatus

(1) Vessel (100 lt. capacity)

(2) Pirani-penning Pressure gauge

(3) Rotary pump

(4) Bellows

(5) Ball-valve

(6) connectors & reducers

Modification proposed:

100 lt. vessel presently available should be replaced by a new 25 lt. Stainless steel vessel.

BOILING OF WATER AT ROOM TEMPERATURE & REDUCTION IN INTENSITY OF SOUND VARIATION IN VACUUM LEVEL

*Apparatus constructed

*Experiment conducted & desired results obtained.

Components of the apparatus:

1)Bell-jar (285 mm diameter)

2)Beaker

3)Thermometer

4)Bell

5)Rotary -pump

6)Supporting stand

7) Aluminium plate

8) Pressure gauge

9) Ball valve & connecting pipes

DESIGN OF VACUUM VESSEL TO BE PURCHASED

* Design of the vessel completed.

Details of the vessel:

(1) Inner diameter -	250 mm
(2) Height -	500mm
(3) Wall thickness -	3 mm
(4) Thickness of upper lid -	10 mm
(5) O-Ring groove -	width (5 mm) ; depth (3.5 mm)
(6) Flange on the upper lid-	(10KF {3 no.} 2 of 30 mm ht.....1 of 50 mm ht.)
(7) Flanges on the vessel-	25 KF (2 no.) ht-40mm .

Chapter 2

DESIGN OF CRYOGENIC APPARATUS

CRYOGENIC APPARATUS

Aim: To measure variation in heat loss across a vacuum insulated test pipeline (carrying liquid nitrogen as the working fluid) with variation in vacuum level and to demonstrate various accessories of a basic cryogenic set-up.

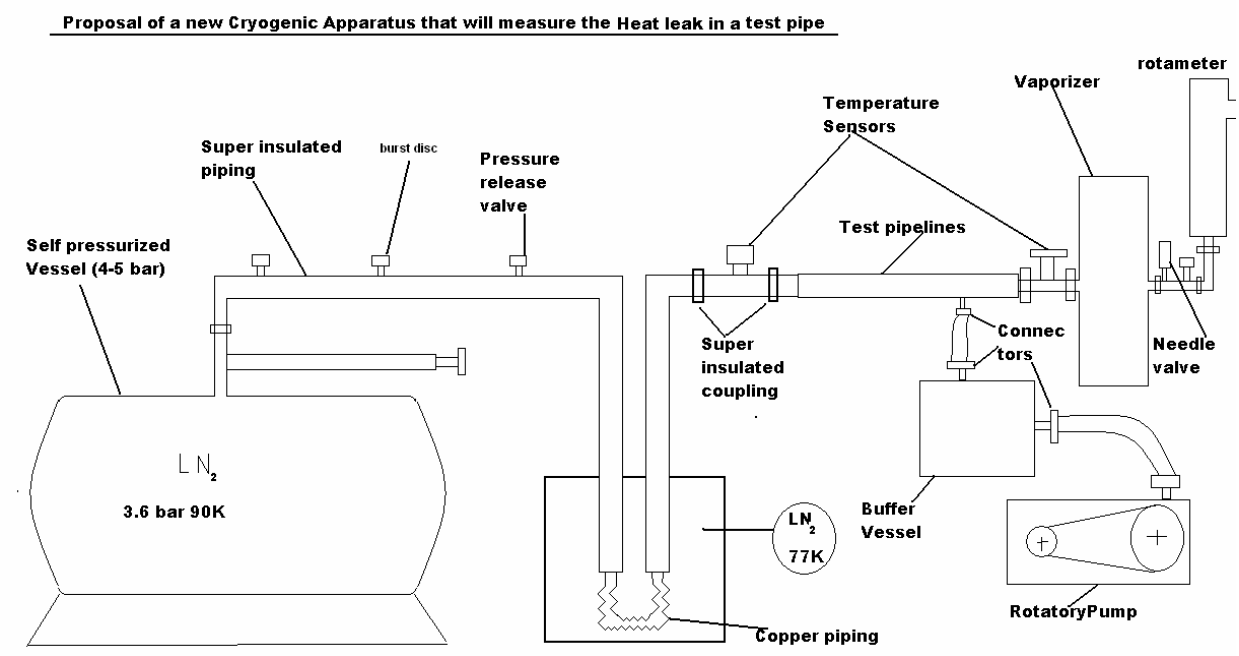


Fig 2.1 sketch showing components of cryogenics apparatus

About the apparatus:

Here we have a self pressurized dewar which will supply us LN_2 at 3.6 bar. Boiling point of LN_2 at 3.6 bar is 90 K.

Extended stem type valve is present which is used so that minimum heat loss takes place. Now by opening valve this pressurized LN_2 flows into the superinsulated piping. Various pressure release valves and burst-disc are placed for the safety purpose. Now this LN_2 at 90K is passed through a open mouth vessel containing LN_2 at 77K. So through copper piping when pressurized LN_2 at 90K comes in contact with LN_2 at 77K it gets subcooled . Now this subcooled LN_2 is made to pass in a test pipeline. This test pipeline is proposed to be vacuum insulated pipeline with temperature sensors across its ends. Level of vacuum is made variable by having a provision for rotary pump so that heat in leak with variation of vacuum insulation may be studied. Rotary pump is not directly connected to the test-pipeline. In between the two there is buffer vessel. Now after passing through test-pipeline LN_2 is made to pass through vapouriser where whole LN_2 is connected into

vapour state which is then made to pass through a rotameter which gives us the mass flow rate of the LN_2.

By knowing this mass flow rate and temperature across the test-pipeline by temperature sensors we can calculate the heat leak in the test-pipeline at a given vacuum.

Now change the vacuum and calculate the heat leak at various pressure by:

$$Q=mCp(T_2-T_1)$$

$Cp(\text{for } LN_2) = 2060$ J/Kg/k (at 3.6 atm)

Plot Graph between Heat leak(Q) and Pressure(P).

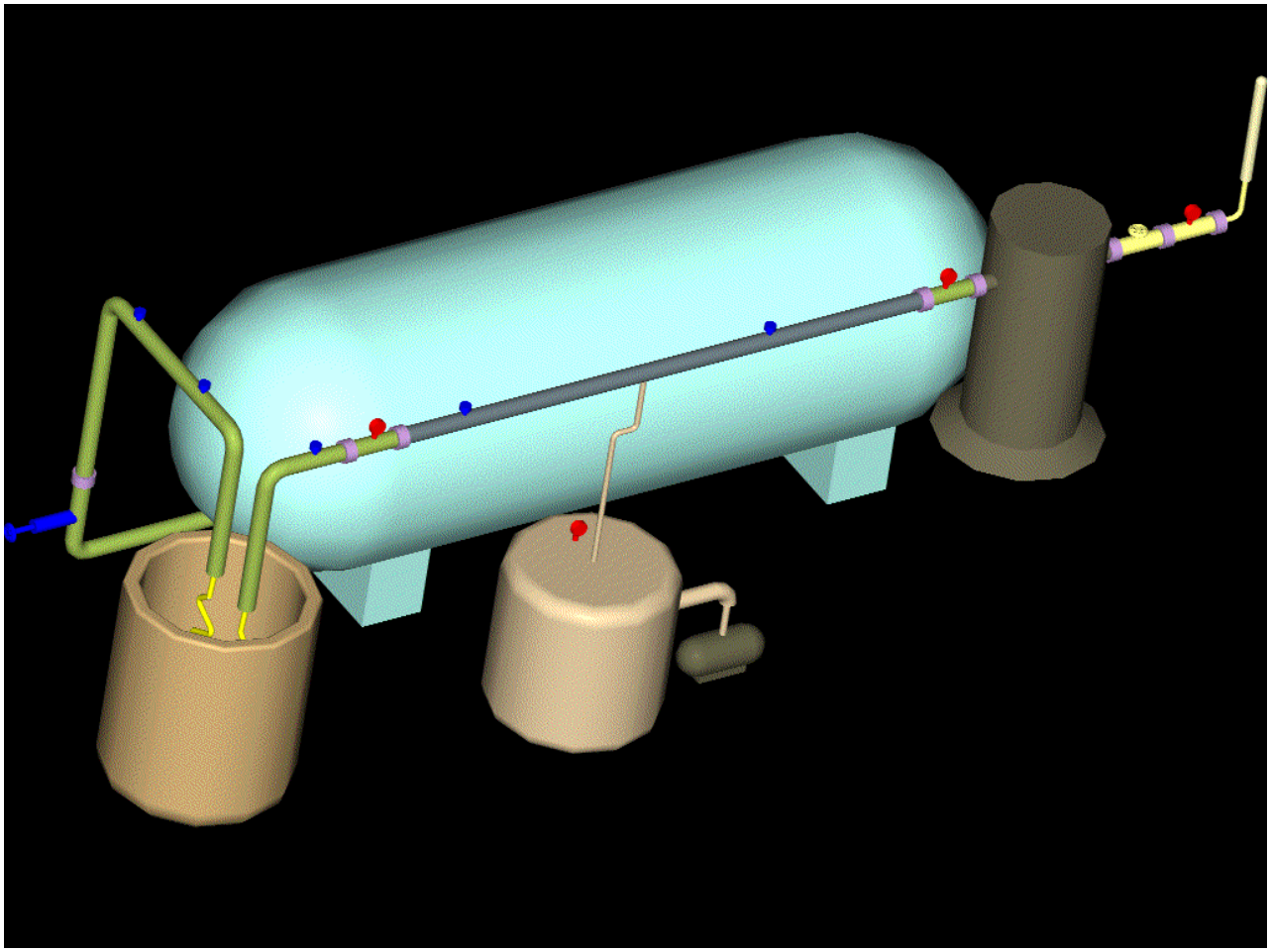


Fig 2.2 Cryogenics apparatus

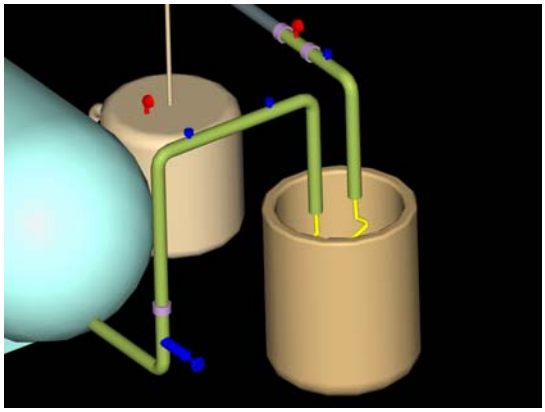


Fig 2.3 sub cooling vessel with pipings

TEST PIPELINE:

Test pipeline is proposed to be a vacuum insulated pipeline with temperature sensor across its ends.

Level of vacuum should be made variable by having a provision for rotary pump so that heat in leak with variation of vacuum insulation may be studied.

Inner diameter of inner vessel, D_i = 10mm

Pipe material = Stainless steel

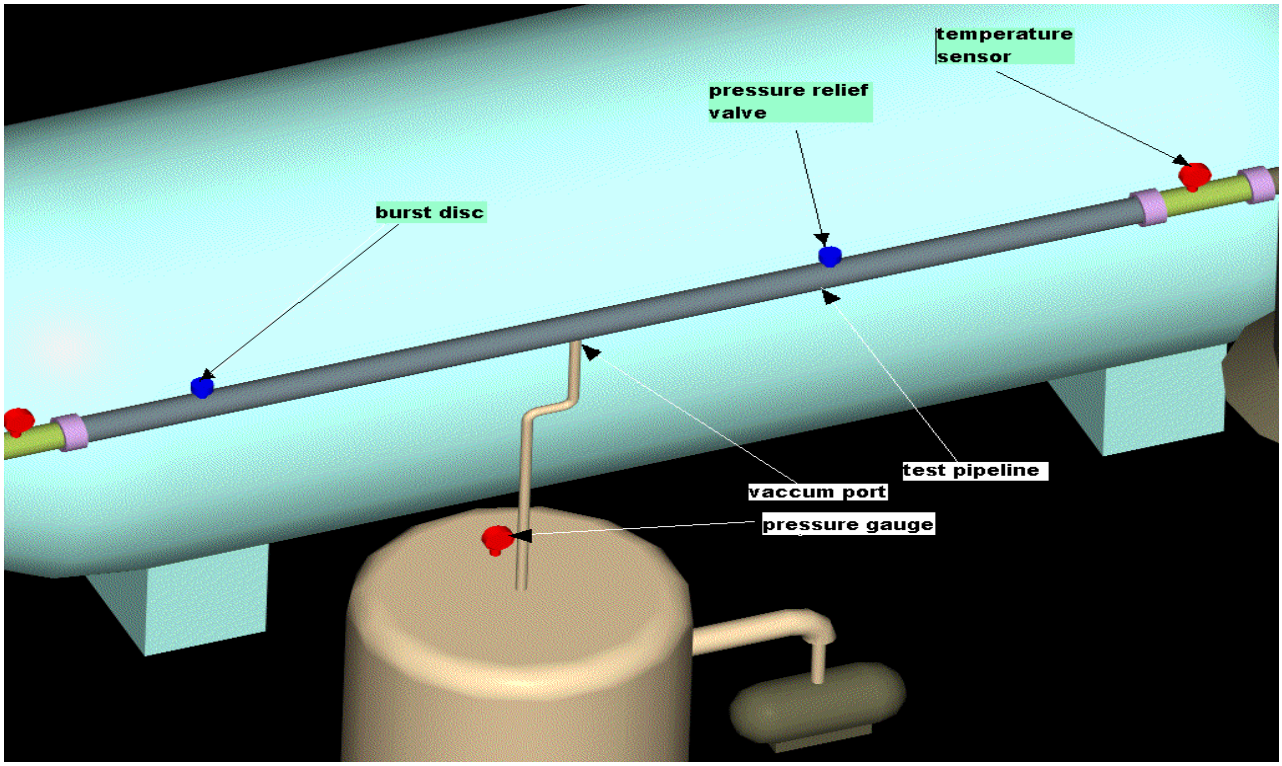


Fig 2.4 test pipeline, burst discs temperature sensors and buffer vessel

Minimum thickness of the test pipeline:

$$t_{min} = PD_i / (2S_a - 1.2P)$$

P= design internal pressure =3.6bar =$3.6*10^5$Pa

S_a =allowable stress

=129.2MPa

D_i=10mm

$t_{min}=1.39*10^{-5}$m =$1.4*10^{-2}$mm

So, we take, thickness of inner pipe

t_i=1mm

For outer pipe:

$$P_{critical} = 2E(t/d_0)^3/(1-y^2)$$

For stainless steel,

poison's ratio ,γ=0.28

E=207 GPa

P_C=1atm

So, $t^3=P_c(1-\gamma^2)*D_0^3/2E$

$t = 6.06*10^{-3}D_0$

for D_o=25mm, t=0.15mm

for Do=50mm, t=0.3mm

for Do=75mm, t=0.45mm

so, thickness can be safely taken as 1mm

t_0=1mm

so,

pipe material = stainless steel

type=vacuum insulation(variable)

inner diameter ,D_i=10mm(thickness t_i=1mm)

outer diameter ,D_o=depend on insulation thickness

outer diameter thickness ,t_0=1mm

LN_2 PROPERTIES ACROSS TEST PIPELINE

Lets take the bulk mean temperature to be 83 k.

$$T_{mean} = 83k$$

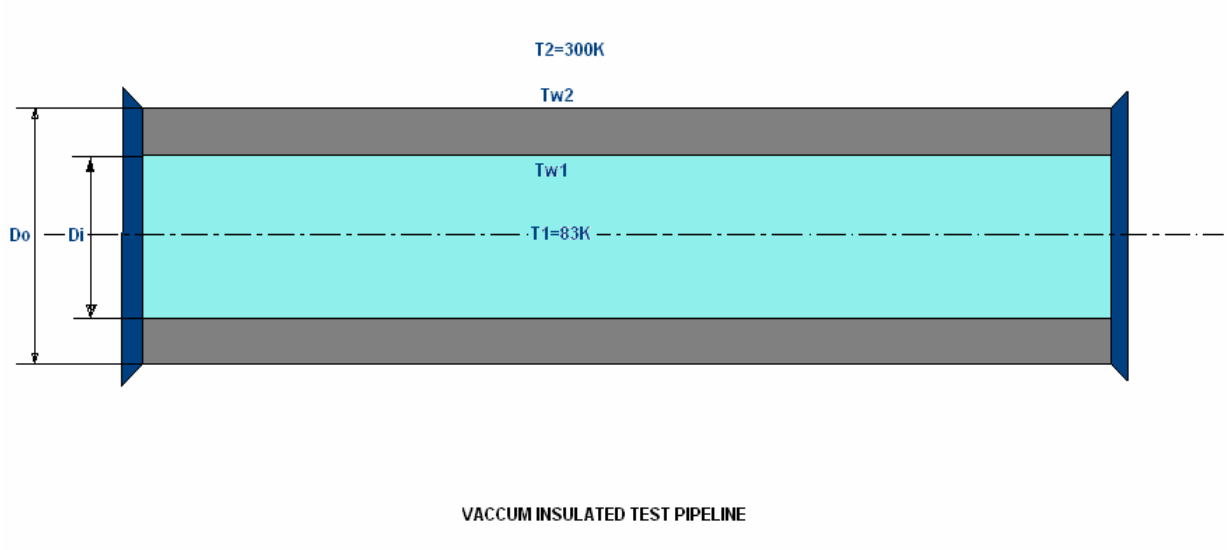


Fig 2.5

At 3.6bar ,83k

Density ,$\rho = 780.33 kg/m^3$

Specific heat ,$C_p = 2.0735 KJ/Kgk$

Viscosity ,$\mu = 130.35 \mu pa\text{-}s$

Thermal conductivity,$k = 134.23 mw/mk$

Prandtl no.,$P_r = 2.01$

Reynolds number ,

$$R_e = DV_{avg}.\rho/\mu = DG/\mu$$

$G = \dot{m}/A_c$=mass flow rate/area

$R_e = 0.01 * \dot{m}/\{130.35 * 10\text{-}6 * \pi/4 * (0.01)^2\}$

$R_e = 9.77 * 10^5 m.$

For $\dot{m} = 0.1 kg/min$, $R_e = 1627.9 = 1628$

(so, laminar flow)

So we assume , $\dot{m} = 0.1 kg/min$

Volume flow rate ,$\dot{V} = \dot{m}/\rho = 1.28 * 10^{-4}\ m^3/min$

Velocity,$v = \dot{V}/area = 1.28 * 10^{-4}/[\pi/4 * (0.01)^2]$

$= 1.63 m/min$

$= 0.027 m/sec$

$= 2.7 cm/sec$

Maximum mass flow rate for laminar flow =0.153kg/min

So,

Mass flow rate, $\dot{m}$=0.1kg/min

Volume flow rate ,$\dot{V}$=0.128lt/min

Velocity ,v=1.63m/min

CAPACITY OF VAPORISER

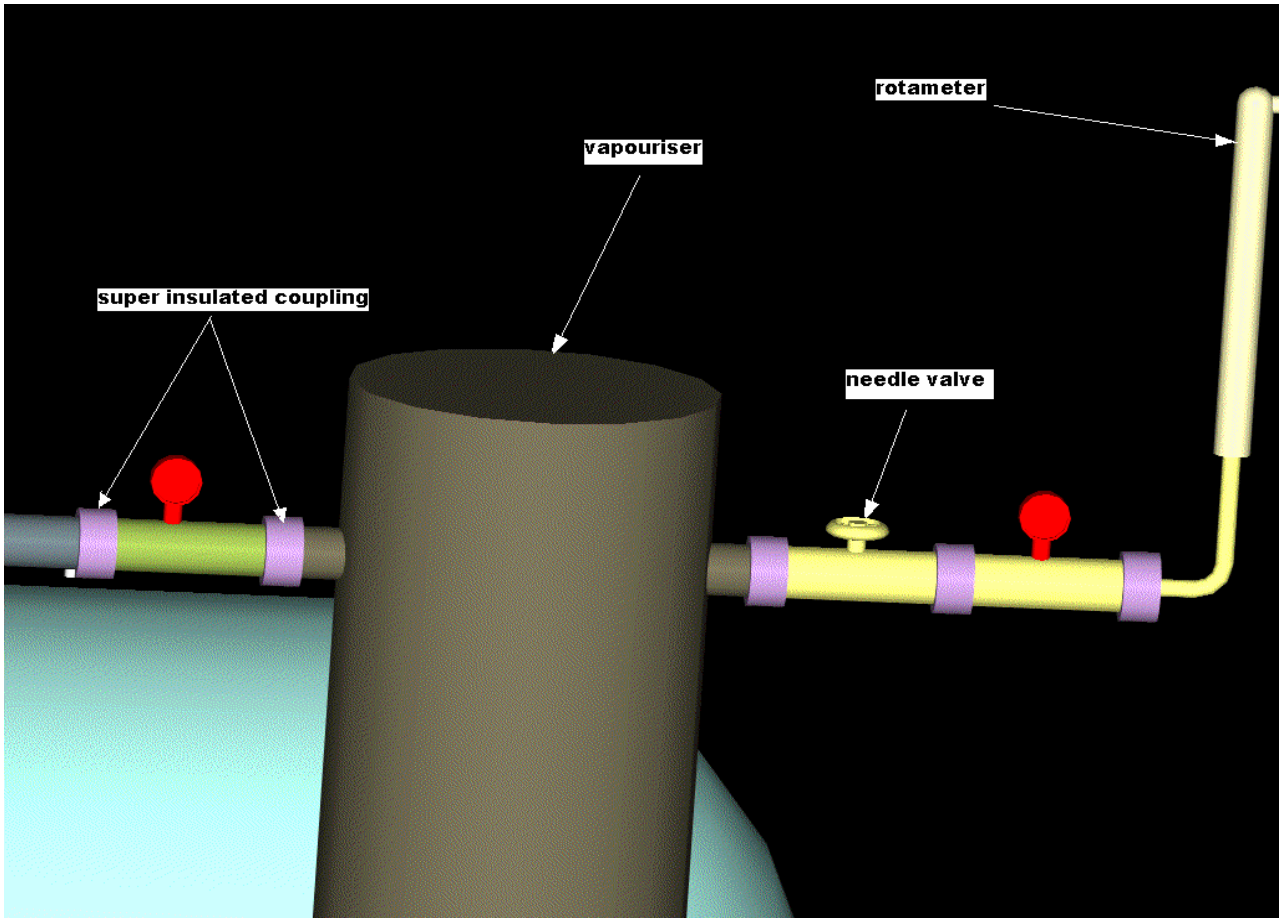


Fig 2.6 Vapouriser

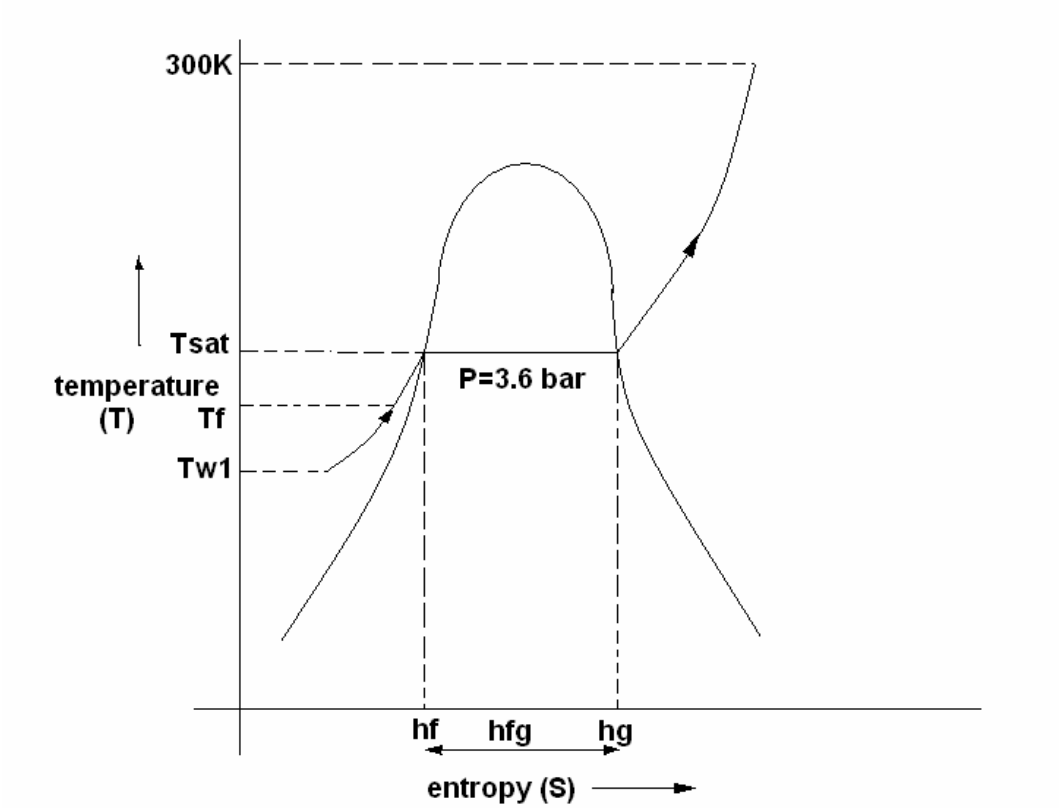


Fig 2.7 T-S diagram for the vapouriser

In vaporizer ,heat is required to convert LN_2at final temperature T_f to gaseous N_2 at 300k.

So,

$Q=m^{\cdot}\{C_{pl}(T_{sat.}-T_f)+h_{fg}+C_{pg}(300-T_{sat.})\}$

$T_{sat.}$=90k at 3.6 bar

$m^{\cdot}$=0.1kg/min

$C_{pl/T=89k}$=2.136KJ/kg.k

$C_{pg/T=90k}$=1.48KJ/kg.k

$C_{pg/T=300k}$=1.0455 KJ/kg.k

H_{fg}=180.9KJ/kg

So,

$Q=-m^{\cdot}C_{pl}\,T_f+m^{\cdot}(C_{pl}\,T_{sat.}+h_{fg}+C_{pg}*210)$

$=-0.1*2136*T_f+0.1(2136*90+180.9*10^3+1482.6*210)$

$=68448.6-213.6T_f$

For T_f=85k,Q_{max}=50KJ/min

For T_f=80k,Q_{max}=51KJ/min

So,we take Q_{max}=55KJ/min

=916.67W

So ,capacity of vaporize required =1KW

HEAT TRANSFER CALCULATIONS AND SPECIFICATION OF TEST PIPE LINE

Heat transfer coefficients for LN2:

Reynolds number, Re=1628

Gratz number ,

$G_z=R_eP_r(D/L)$

$=1628*2.01*0.1/L$

$=32.72/L$

Nusselt number ,

$N_u=3.657+0.0668G_z/(1+0.04G_z^{2/3})$

$=3.657+0.668*32.72L^{-1}/[1+0.04*(32.72)^{2/3}]L^{-2/3}$

For L=1m

$N_u=5.21$

$N_u=h_i*D_i/Kt$

$h_i=N_u*K_t/D_i=5.21*0.134*3/0.01$

$=69.9$

$h_i=70W/m^2k$

Heat transfer coefficient for air:

At 300k,1atm

For gases air,

$\rho=1.177kg/m^3$

$C_p=1.005KJ/kg.k$

$\mu=18.47*10^{-6}Pa/s$

$k=26.24mW/mk$

$P_r=0.708$

$ß_t=1/T=1/300k^{-1}$

$G_r=g*ß_t*\rho^2\Delta TL^3/\mu^2$

$.\Delta T=T_2-T_{w2}=x$

$G_r=[9.81*(1/300)*(1.177)^2*\Delta T*L^3]/(18.47*10^{-6})^2$

$=1.327*10^8*\Delta T*L^3$

$G_r.P_r=9.4*10^7*\Delta T*L^3$

$=9.4*10^7 xL^3 (x=\Delta T)$

For laminar flow

$N_u=0.36+[0.518*(G_rP_r)^{1/4}]/[1+(0.559/P_r)^{9/16}]^{4/9}$

$=0.36+[0.518*(9.4*107x)^{1/4}*L^{3/4}]/1.322$

$N_u=0.36+38.57x^{1/4}L^{3/4}$

$h_0=N_u*K_t/D$

$=(0.36+38.57x^{1/4}L^{3/4})*0.02624/0.03$

$h_0=0.3+33.73x^{1/4}$ L=1m

D_0=30mm

Heat transfer coefficient for annular spacing

$T_{mean}=(T_{w1}+T_{w2})/2$

Characteristic length, $l=(D_2-D_1)/2=(0.028-0.012)/2$

$=0.008cm$

$\beta_t=1/T_{mean}$

$G_r=g\beta_t\rho^2\Delta TL^3/\mu^2$

If G_rP_r <1000(suppressed motion)

$N_u=[(D_2/D_1)-1]/\ln(D_2/D_1)=B$

If $10^3<G_rP_r<10^6$(cellular motion)

$N_u=0.11B(G_rP_r)0.29$

If $10^6<G_rP_r<10^8$ (Turbulant)

$N_u=0.40B(G_rP_r)^{0.20}$

$N_u=h_cl/K_t$

$A_i=\pi D_iL$

Radiation heat transfer

For maximum radiation heat transfer

Let $T_1=T_{w1}$=80k

$T_2=T_{w2}$=300k

F_e=emissibity factor $=e_1e_2/[e_2+A_1/A_2(1-e_2)e_1]$

For S.S ,e_1=0.048

e_2=0.08 [Thomas flynn]

$Q_r=\sigma F_e A_1(T_2^4-T_1^4)*F_{1-2}$

F_{1-2}=configuration factor=1

F_e=0.048*0.08/[0.08+12/28(1-0.08)0.048]

=0.04

$Q_r=5.67*10^{-8}*0.04*\pi*0.01*1*(300^4-80^4)$

Q_r=0.57W/m for L=1m

D_0=30mm

So, it is less in comparison to convective losses ,so can be neglected for calculation

Conduction losses due to residual gases:

Inter molecular distance ,

$d=\mu/p(\pi RT/2g_c)^{1/2}$

where μ=viscosity

p=pressure

if $d>(D_2-D_1)/2$

Then the residual conduction is considered .

Here,

$Q=(\gamma+1)/(\gamma-1)*\alpha*(R/8\pi MT)^{1/2}*p(T_{w2}-T_{w1})*\pi D_1 L$

$\gamma=C_p/C_v$

α=accommodation factor=$\alpha_1\alpha_2/[\alpha_2+\alpha_1(1-\alpha_2)A_1/A_2]$

accommodation coefficient ; α_1=1 (77k)

α_2=0.85 (300k)

T=300k

T_{w1}, T_{w2} => outer and inner wall temperature

At 10^{-2} mbar

$D=\mu/p(\pi RT/2g_c)^{1/2}$ $p=10^{-2}$ mbar

=1pa

$=6.79*10^{-3}$

$=0.007=0.008=(D_2-D_1)/2$

So residual conduction may be considered

$\alpha=\alpha_1\alpha_2/[\alpha_2+\alpha_1(1-\alpha_2)A_1/A_2]=0.93$

$Q=(1.4+1)/(1.4-1)*0.93*[8314/(8\pi*28.97*300)]^{1/2}*(T_{w2}-T_{w1})*\pi*0.01*L$

$Q=0.034(T_{w2}-T_{w1})$

For continuum range ($P>10^{-2}$ mbar)

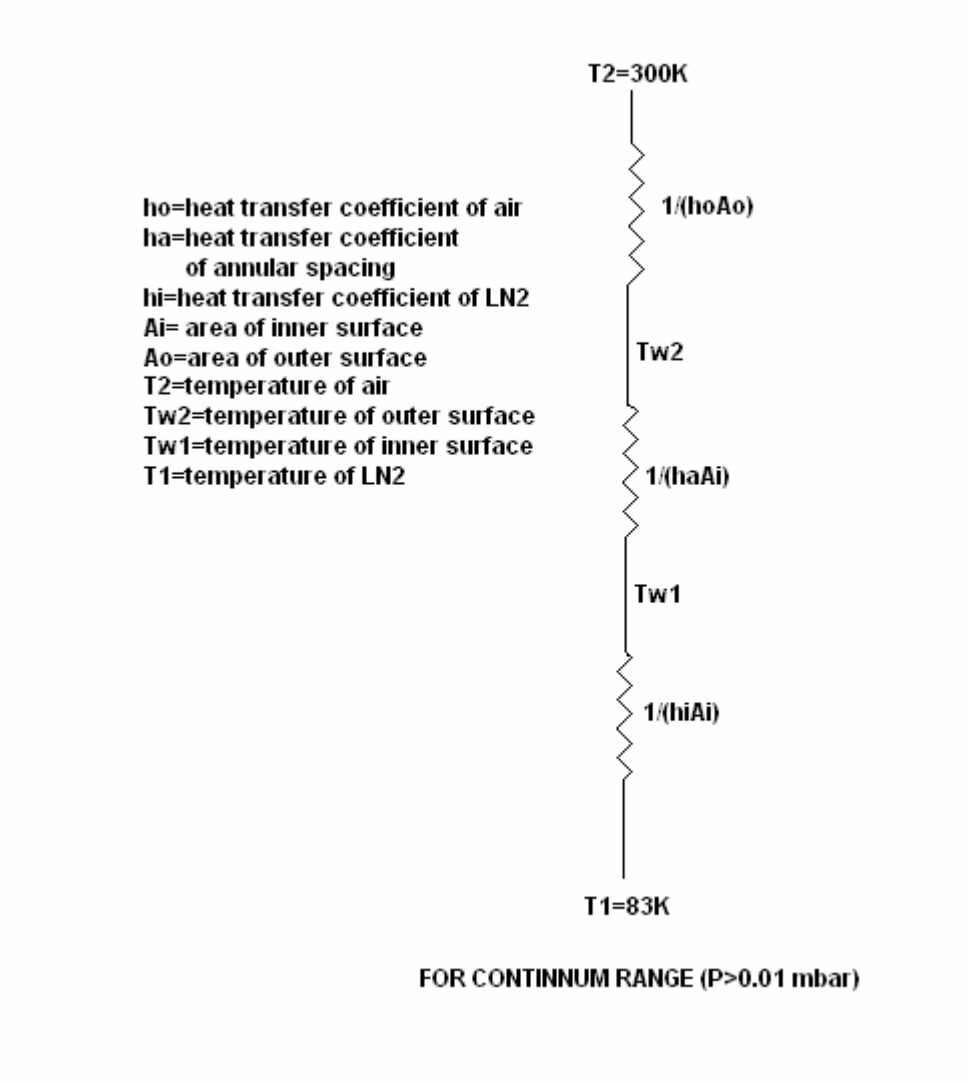


Fig. 2.8 equivalent circuit for continnum range

i.e

$h_0A_0(T_2-T_{w2})=h_iA_i(T_{w1}-T_1)=h_aA_i(T_{w2}-T_{w1})*(T_2-T_1)/[1/h_0A_0+1/h_iA_i+1/h_aA_i]$

for molecular range ($p<=10^{-2}$ mbar)

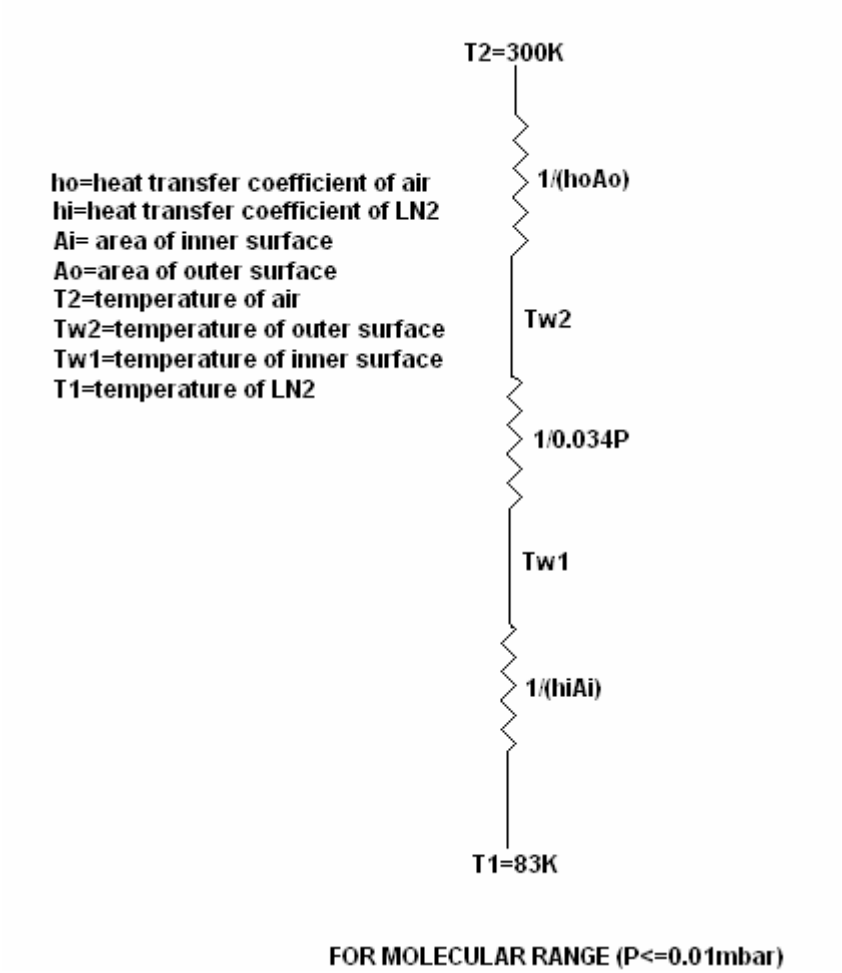


Fig. 2.9 equivalent circuit for molecular range

$h_0A_0(T_2-T_{w2})=0.034(T_{w2}-T_{w1})=h_iA_i(T_{w1}-T_1)=(T_2-T_1)/[1/h_0A_0+1/0.038+1/h_iA_i]$

for molecular range ,at 10^{-2} mbar

$h_0A_0\,(T_2-T_{w2}) = (T_2-T_1)/[1/h_0A_0+1/h_iA_i+1/0.034]$

$x=T_2-Tw_2$

$= (T_2-T_1)/[1+h_0A_0(1/h_iA_i+1/0.034)]$

$h_i = 70W/m^2k$

$h_0=0.3+33.73x^{1/4}$

$x=T_2-T_1/(1+2.87h0)$

$x+2.87x\ (0.3x+33.73x^{1/4})=217$

$1.84x+94.8x^{5/4}=217$

$x=1.92k$

$T_{w2}=298.08k$

$0.034(T_{w2}-T_{w1})=h_iA_i(T_{w1}-T_1)$

$0.034T_{w2}+h_iA_iT_1=T_{w1}(h_iA_i+0.034)$

$T_{w1}=86.27k$

At 10^{-3}mbar

$Q=0.0034(T_{w1}-T_{w2})$

$x=(T_2-T_1)/[1+h_0A_0(1/h_iA_i+1/0.0034)]$

$x=217/(1+27.8h_0)$

$x+27.8x(0.3+33.73x^{1/4})=217$

$8.34x+937.7x^{5/4}=217$

$x=0.308k$

$T_{w2}=299.7k$

$T_{w1}=83.33k$

FINDING WALL TEMPERATURES (T_{w1}andT_{w2})IN CONTINUUM RANGE

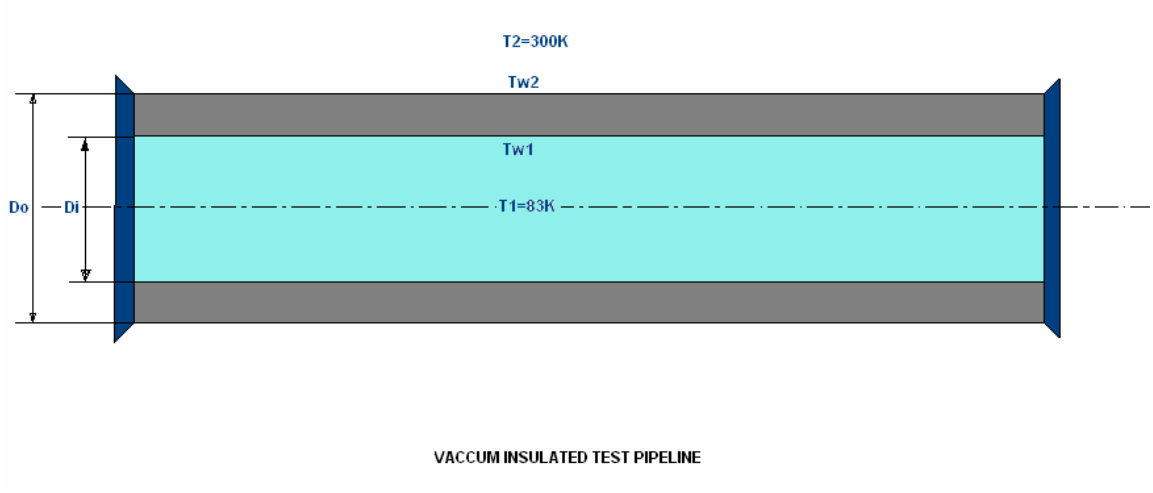


Fig 2.10 test pipeline showing temperatures at various points

Known values: $T_1=83k$ $h_i=70W/m^2k$

$T_2=300k$ A_i,A0,L

Unknown values : $T_{w1}$and T_{w2}

(also h_a depends on property at $(T_{w1}+T_{w2})/2$)

$h_0=0.3+33.73x^{1/4}$

Equation:

$h_aA_0(T_2-T_{w2})=h_iA_i(T_{w1}-83)=h_aA_i(T_{w2}-T_{w1})=(T_2-T_1)/[1/h_0A_0+1/h_iA_i+1/h_aA_i]$

To find the wall temperature ,we have developed iteration process which is as follows:-

1. Assume any values of T_{w2} and T_{w1}(e.g 295k and 85k)
2. calculate ha (for annular) using properties at these values i.e $(T_{w1}+T_{w2})/2$

3. use heat transfer equation mentioned above
4. find new values of T_{w1} and T_{w2} from these equation .
5. now, calculate h_a at new value of $(T_{w1}+T_{w2})/2$.
6. follow step 2 to5 until two approx. same value of T_{w1} and T_{w2} are obtained .

Since the calculation involved in iterative process may be cumbersome , so we have we have written a C++ program which can be run for desired values of iteration.

C++ Program for iteration process

```
#include<iostream.h>
#include<conio.h>
#include<stdio.h>
#include<stdlib.h>
#include<math.h>
int main()
{
  float h0=0, hi=69.36, ha=0, t1=83, error=0, t2=300, L1=0, tw1=85, tw1n=0, tw2=295,
tw2n=0, m=0, n=0, Tm=0, La=0, Pr=0.708, Pra=0, Kt=0, Nu=0,
Nua=0,B=1.57,D1=.01,D2=0.03;
//h0, ha, hi=heat transfer coefficients of air, annular spacing, Ln2 respectively, Pra= prandtl
no., Nu= nusselt no.
  double Gr=0,Gra=0,y=0,mu=0,row=0,Bt=0,z=0;
//Gr=Grashoff no.,Gra=Gratz no., mu=viscosity, row=density,
  int i=0,L=1;
  for(i=1;i<=10;i++)
        {
        Gr=1.33*pow(10,8)*(t2-tw2)*pow(L,3);

        Nu=0.36+(0.518*pow((Gr*Pr),0.25))/(pow((1+pow((.559/Pr),(9.0/16))),(4.0/9)));
              h0=0.875*Nu;
              cout<<"\nenter the values of  density , viscosity and Prandlt thermal
conductivity No at temperature= "<< (tw1+tw2)/2<<"\n";
              cin>>row;
              cin>>mu;
              cin>>Pra;
```

```
        cin>>Kt;
        Tm=(tw1+tw2)/2.0;
        La=0.008;
        Bt=1/Tm;
        Gra=(9.81*Bt*pow(row,2)*(tw2-tw1)*pow(La,3))/pow(mu,2);
        y=Gra*Pra;
        if(y<1000)
        Nua=B;
                else if(y<1000000)
                        Nua=0.11*B*pow(y,0.29);
                                else if(y<100000000)
                                        Nua=0.40*B*pow(y,0.20);
    else
    {cout<<"\n error in calculating Nua.....value exceeding limit...";
  exit(0);
    }
    ha=(Nua*Kt)/La;
    cout<<"\nho=  "<<h0;
    cout<<"\nha=  "<<ha;
        getch();
    z=(1.0/ha)+(1.0/hi);
cout<<"\nz= "<<z;
    L1=pow(L,0.75);
    for(float x=.2;x<=300;x=x+.2)
    {
    error= (((0.315*x)+((33.76)*(pow(x,1.25))))*z*3)+x;
    if ((error>=210&&(error<=220))
    {cout<<"\n"<<x;
        break;
        }
    }
        if(x>=300)
        cout<<"\n x not in range";
    tw2n=t2-x;
```

```
        tw1n=(ha*tw2n+hi*t1)/(hi+ha);
        m=tw1-tw1n;
        n=tw2-tw2n;
        cout<<"\nouter wall temperature(tw2)="<<tw2n;
        cout<<"\ninner wall temperature(tw1)="<<tw1n;
                if((m>=-1&&m<=1)&&(n>=-1&&n<=1))
                 {cout<<"\n\n\nconverged";
    getch();
                 exit(0);
                 }
                 else
                 {tw1=tw1n;
                 tw2=tw2n;
                 }
        }
        return(0);
         }
```

Results:

Pressure(P)	Wall Temp. Tw1 and Tw2 (K)	Heat In leak Q (watt/m)	Final Temp. for Ti = 77 K (K)	Final Temp. for Ti =79 K (K)
1 atm	Tw1=107.9 Tw2=290.27	54.76	92.9	94.9
0.5 atm	Tw1=101.1 Tw2=292.6	39.8	88.6	90.6
10 mbar	Tw1=93.37 Tw2=295.2	22.8	83.6	85.6
0.01 mbar	Tw1=86.27 Tw2=298.08	7.19	79.09	81.6
0.001 mbar	Tw1=83.33 Tw2=299.7	0.72	77.02	79.02

Table2.1 final result showing variation of heat inleak and final temperature with pressure

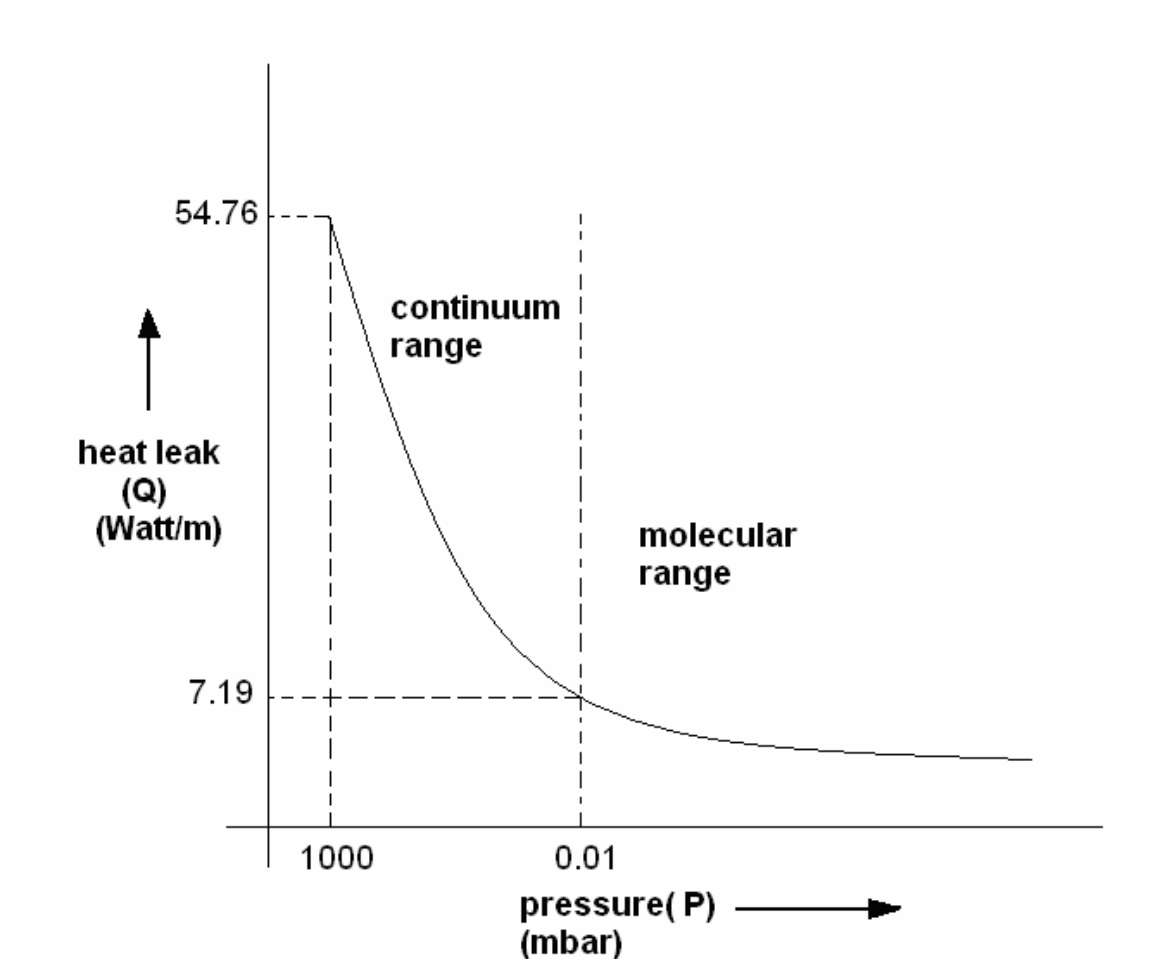


Fig 2.11variation of heat leak with pressure

So heat inleak through the vaccum insulated test pipeline decreases with increase in vaccum level.

SAFETY DEVICES

Inner vessel pressure relief valve to be designed at 10% more than designed gauge pressure;

Where ; gauge pressure = Absolute pressure –atmospheric pressure

So, p (max) = (set gauge pressure) * (1.10) + (atmospheric pressure)

= (3.6-1)*1.10+1

= 3.86 bar

= 4 bar {reference cryogenics systems BARRON }

BURST DISC

It is to be designed at 20%more than designed gauge pressure.

p (max) = (3.6 -1) *1.20 +1

=4.12 bar

MATERIALS REQUIRED

1) Self pressurizing storage vessel-(for obtaining liquid nitrogen at 3.6 bar)

2) Super insulated pipeline(stainless steel)

(with one end connected to self pressurizing vessel &other to the copper pipings)

Length=1m

Inner diameter =10mm

Outer diameter=30mm(with pressure relief valve &burst disk)

3) Super insulated pipeline(stainless steel)

(with one end connected to copper pipings & other end to test pipeline)

Length=0.5m

Inner diameter=10mm

Outer diameter=30mm

4) 0pen wide mouth liquid nitrogen container

5) Coiled copper pipings

6) Two temperature sensors(to be connected at both ends of the test pipeline)

7) Vacuum insulated (variable) test pipeline (with a connect to rotary pump for evacuation)(with pressure relief valve & burst disc)

Material - stainless steel

length =1m to 1.25 m

inner diameter =10mm

outer diameter =30mm

8)Vaporiser- 1 KW capacity

9)Rotameter(at atmospheric condition)

10) Needle valve (for operating between vaporizer & Rota meter)

11) Couplings & other such fittings-(for connecting various pipelines together)

OTHER SPECIFICATIONS-

Mass flow rate= 0.1 kg/min

Volume flow rate = 0.128 lit/min (for liquid nitrogen)

= 87 lit/min(for vapour nitrogen)

Velocity =1.63 m/min

Inner diameter; Di = 10mm

Outer diameter; Do =30 mm } for all pipelines

Minimum thickness = 1mm

Capacity of vaporizer = 1KW

Chapter 3

VACUUM: A BRIEF OVERVIEW

VACUUM

The atmospheric air around us is said to contain nearly 2.5*10^19 molecules for every cubic centimeter of space. Any given space having molecular density less than this is said to be under vacuum conditions.

VACUUM TECHNOLOGY:

The technology dealing with the production of such reduced-pressure environments using different scientific concepts is known as “vacuum technology”.

UNITS:

In SI units, the unit of pressure is N/m^2 or Pascal, and in the CGS system of units it is dyne/cm^2.

1 torr =1 mm of Hg =1/760 atm.

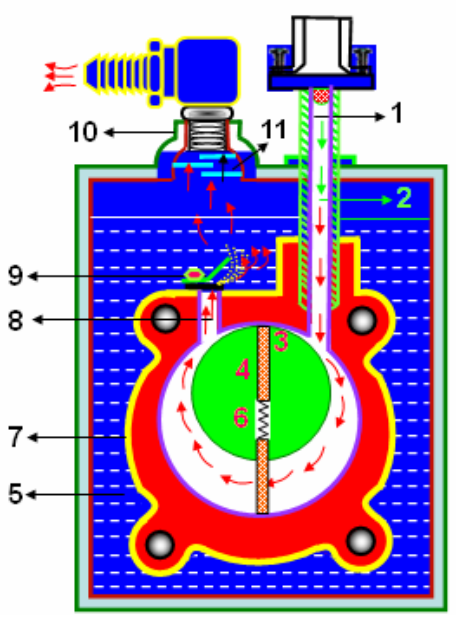
1 mbar=100 Pascal=1/1013 atm.

THROUGHPUT AND PUMPING SPEED:

The pumping speed is defined as the volume of gas per unit of time, dV/dt, which the pumping device removes from a system at the pressure existing at the inlet to the pump. The pumping speed is expressed in litre/s, m^3/hr, etc.

Throughput Q is defined as the product of the pumping speed and the inlet pressure, that is, Q=PS=P(dV/dt).

ROTARY VANE PUMPS:



1. Inlet tube, 2. Inlet port, 3. Top seal, 4. Vanes, 5. Oil,
6. Rotor, 7. Stator, 8. Exhaust port, 9. Exhaust flap valve with backing plate, 10. Exhaust outlet, 11. Oil splash baffles

Fig 3.1 ROTARY VANE PUMP

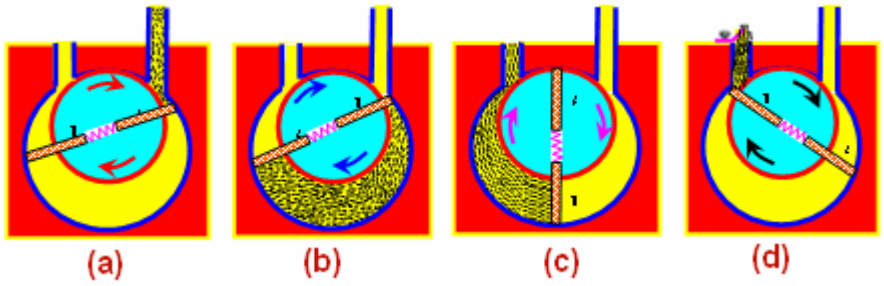


Fig 3.2 Pumping Mechanism inside Rotary Vane Pump

It has a cylindrical steel rotor located eccentrically in a cylindrical stator housing, almost touching the stator surface at the top. The rotor is slotted at its diameter to take two spring-loaded vanes which bear tightly against the inner surfaces of the stator. The stator is a steel cylinder the n=ends of which are closed by suitable plates, which hold the shaft of the rotor. The stator is pierced by the inlet and exhaust ports which are positioned respectively a few degrees on either side of the vertical. The inlet port with a dust filter is connected to the vacuum system and the exhaust port is provided with a valve, which may

be a metal plate moving vertically between arrester plates, or a sheet of Neoprene, which is constrained to hinge between the stator and a metal backing plate.

The lie of contact as the top seal between rotor and stator must have a clearance of 2-3 microns. Whole stator-rotor assembly is submerged in suitable oil, which serves as a sealant, coolant and lubricant. A film of oil is used on all moving parts. The rotary oil-sealed pumps normally operate at speeds of several hundred revolutions per minute. They are air-cooled in the smaller sizes and water-cooled in larger sizes. Pumps with capacities ranging from a few tenths to over a thousand cubic feet per minute are available commercially.

As vane A passes the inlet port, the vacuum system is connected to the space limited by the stator, the top seal, the rotor and vane A. The volume of this space increases as the vane sweeps round, thus producing a pressure decrease in the system. This continues until vane B passes the inlet port, when the volume of the gas evacuated is isolated between the two vanes. Further rotation sweeps the isolated gas around the stator until vane A passes the top seal. The gas is now held between vane B and the top seal, and by further rotation it is compressed until the pressure is sufficient to open the exhaust valve and the gas bubbles out through the oil to the atmosphere.

Since both vanes operate in one rotation of the rotor, a volume of gas equal to twice that indicated is displaced by the pump. Thus the volume rate at which the gas is swapped around the pump referred to as pumping speed S is given by,

$S=2*V*n$

where V is the volume between vanes A and B and n is the number of rotations per unit time. The pumping speed is quoted at pressure prevailing at the inlet and hence is expected to be constant regardless of the pressure as V is constant. But in practice the pumping speed is fairly constant at high pressures, falls appreciably at lower pressures, and becomes zero at ultimate pressures. In a rotary pump the gas is compressed into a small but finite dead volume before getting discharged. When the system pressure becomes so low, at maximum compression, the gas pressure is still less than that of the atmosphere and it cannot be discharged from the pump. The pump oil is usually hydrocarbon oil chosen for its low vapour pressure.

The pump should be vented back to the atmosphere as soon as it is stopped as otherwise the oil in the pump will enter the system due to suction. During unattended operation, this situation may occur due to power failure. Solenoid valves can also be used to close off the

pump from the rest of the system and to vent it to atmospheric pressure if the power is turned off.

The contamination from the pump mainly arises due to hydrocarbon pump fluids, where their vapour pressure and that of their cracking products at room temperature is in the range of several milli-torr. This hydrocarbon contamination can be minimized with liquid nitrogen or absorbing traps.

Most vacuum pumps are available with a feature called gas ballast, or vented exhaust. This is a device to minimize condensation of vapours in the pump. The gas ballast feature helps to minimize the compression ratio to which the condensable vapour is subjected. Atmospheric air is admitted to the pump body during the compression stroke. Since the exhaust valve opens when the pressure inside the pump is just over the atmospheric, the mixing of non condensable air with the condensable vapour reduces the ratio of compression for the partial pressure due to the condensable vapour. As might be expected, this causes some deterioration of the ultimate pressure of the pump, especially in a single-stage pump. For this reason the gas-ballast valve is usually adjustable, so that, once the gas-ballast is no longer needed, the good ultimate pressure of the pump can be regained by closing the ballast.

The oil sealed rotary pump is the usual choice as a fore pump, that is, the pump providing the starting vacuum for different high vacuum pumps(diffusion pump, turbo-molecular pump, cryopump etc). At present rotary pumps are available in a wide range of pumping speeds typically from 45 litre/min to around 7800 litre/min. The ultimate pressure attainable using these pumps can be as low as 1.3*10e-4 mbar.

DIFFUSION PUMPS:

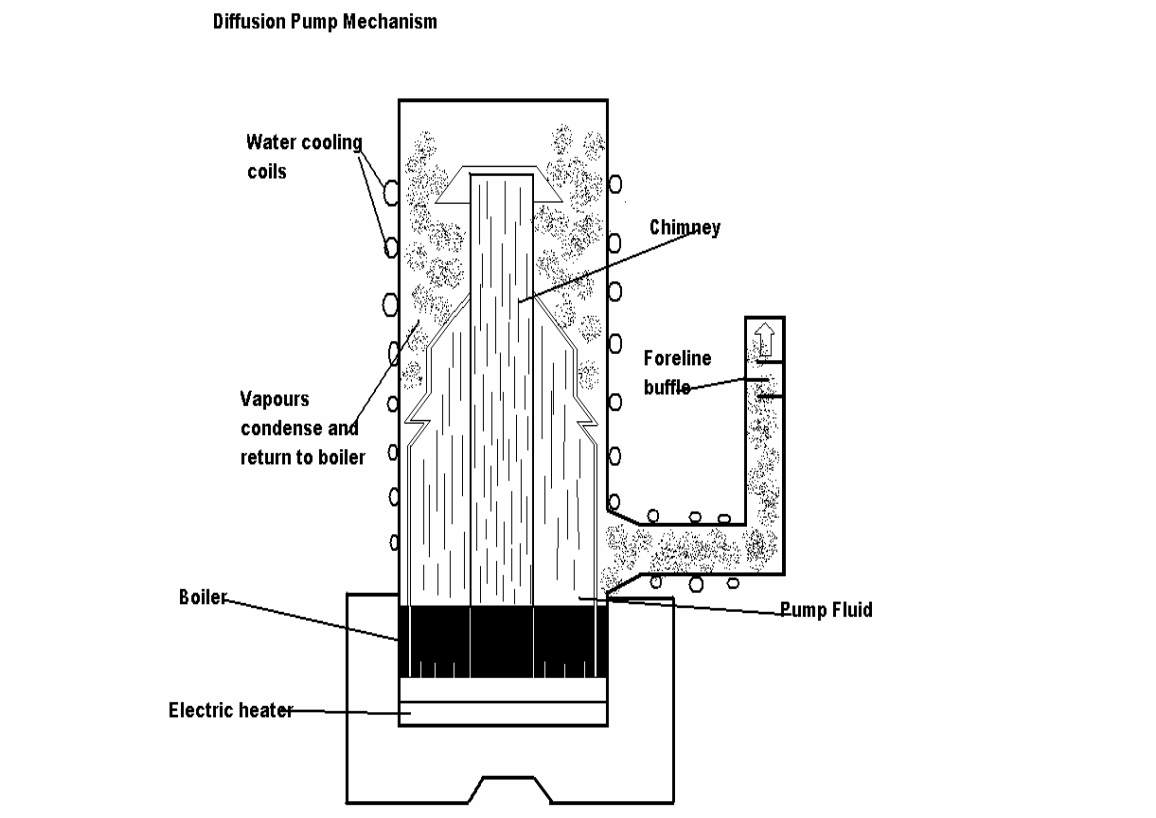


Fig 3.3 diffusion pump

Diffusion pumps are vapour jet pumps or vapour ejector pumps designed for pumping rarefied gases in the high –vacuum range (<10^-2 torr) of pressures. These are called "diffusion" pumps because of the fact that the molecules of the pumped gas penetrate the vapour jet in a manner resembling diffusion of one gas to another.

Diffusion pumps are used when constant high speeds for all gases are desired for long periods of time without attention. Diffusion pumps cannot discharge directly into atmosphere. a mechanical pump is required to reduce the pressure into

the vacuum system to the correct operating range. The mechanical pump is then used to maintain proper discharge pressure conditions for the diffusion pump .

a pumping fluid of low vapour pressure is boiled in the boiler. The oil vapour flows up through the jet chimneys, reverses its direction at jet caps and emerges out (downwards) from the jet nozzles at supersonic velocities. The oil molecules condense on the pump walls which are water cooled and flow in the form of an oil film, back down to the boiler where the oil is reboiled and evaporated. Gas molecules present in the chamber above the jet assembly diffuse into the vapour stream (jet) where they are given the download momentum due to collision with heavier oil molecules. Thus the molecules are forced by

the jet into the region of high pressure in the lower section of diffusion pump. The pressure here is high enough for the backing rotary pump to have a finite pumping speed so the accumulated gas molecules are drawn off through the fore – vacuum line.

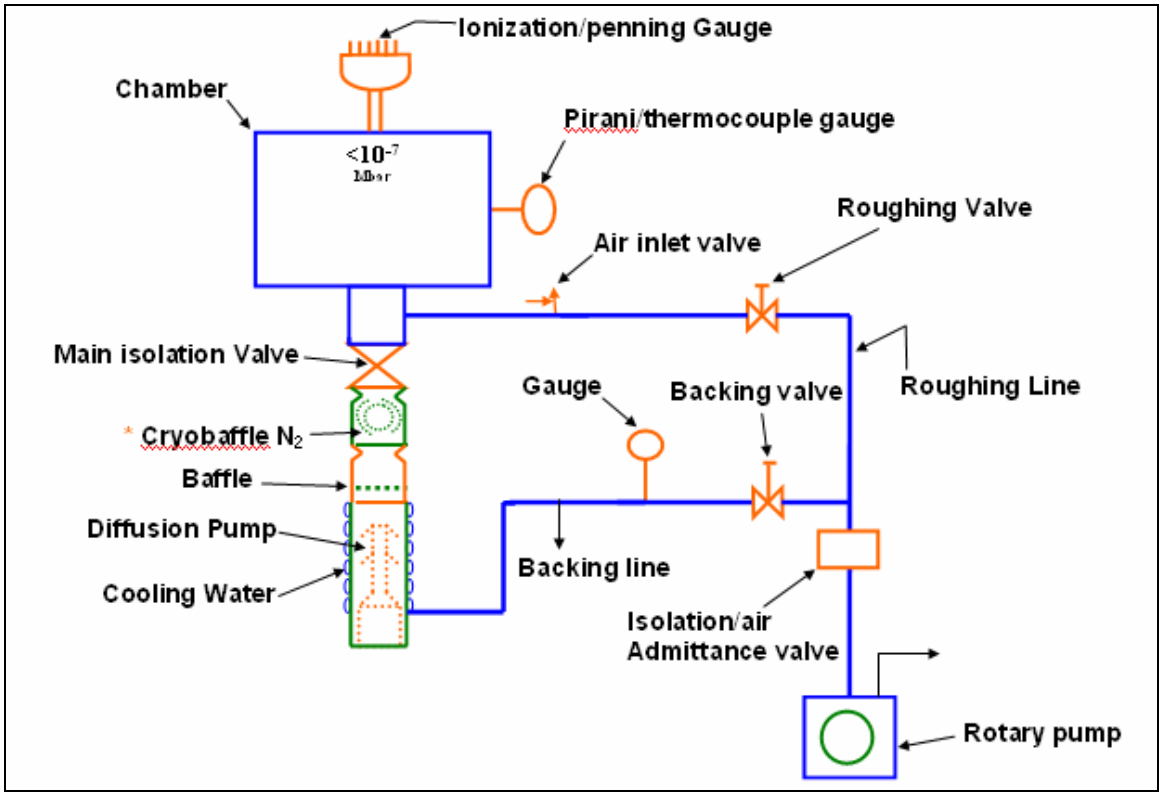


Fig 3.4 Vacuum Pumping System

By providing a cold trap between the diffusion pump and the region being evacuated, pressures far below the vapour pressure of the pump liquid may be achieved.

The diffusion pump fluid can be continuously contaminated by the mechanical foe-pump due to the transfer of low vapour pressure mechanical pump oil. This transfer can be eliminated by the use of a suitable adsorption /condensation trap in the fore line.

Back streaming can be effectively stopped by properly designed trap, but only at the expense of reduced pumping speed.

The pumping speed for a vapour diffusion pump is constant in its working range and limited by the pump mouth diameter, since this determines the number of molecules per second entering the pump and getting entrained in the supersonic jet. Pumps are commercially available with speeds ranging from 100 l/s to 45000l/s.

In fact the speed varies inversely with the square root of M, where M is the molecular weight of gas being pumped.

The pumping speed of the diffusion pump(for air at 20 degree Celsius) is given by S=11.6AH l/s, where A is the area of the intake annulus (in cm sq) around the top jet cap and H is ho-factor, whose value is usually in the range of 0.3 to 0.5.

A typical arrangement of high vacuum pumping module is commonly used in laboratories with diffusion pump, rotary pump, valves and piping networks. During operation the backing valve is opened and roughing valve closed. The main isolation valve is used to isolate chamber from pump when required .the roughing valve is used to pump the chamber independently by a rotary pump. Precautions should be taken not to expose the hot pump oil to atmosphere to avoid oxidation. Vapour diffusion pumps, with correctly chosen accessories and appropriate pumping fluid can produce ultimate pressures down to 10^-11 torque.

SORPTION PUMPS:

Gas molecules may be removed from the gas phase if they become attached to as solid surface, or if they penetrate into a solid. The first phenomenon is termed “Adsorption” and second is “Absorption”. “Sorption pumping” refers to such processes utilized to produce vacuum conditions. The attracting forces in gas adsorption by a solid may be physical (physisorption) or chemical (chemsorption).

The solid which takes up the gas is known as the adsorbent and the gas being removed is known as adsorbate.

There are three sorbent materials which have widespread use in vacuum production, namely activated charcoal, activated alumina and molecular sieves.

CONSTRUCTION AND ACTION OF SORPTION PUMPS

Degassed zeolite pellets cooled to liquid nitrogen temperature can hold large quantities of condensable gases.

The sorption pump consists of a stainless steel body with internal copper fins to facilitate hest transfer to the zeolite charge. A liquid nitrogen container is attached to three support brackets. As the temperature of zeolite (molecular sieves) falls, it sorbs more gas from the system to cause reduction in the pressure .after pumped down to the equilibrium pressure,

the valve to the system is closed. At this stage the molecular sieve is saturated. The reactivation can be carried out by allowing the pump to warm the room temperature, care being taken to vent the pump. Sometimes it is necessary to take the molecular sieves to 300 deg C for several hours to drive off water vapour. The rubber stopper acts as the safety pressure release valve.

Sorption pumps are generally used to pump from atmospheric pressure to 10^-2 torr provide the sorptive capacity is correctly matched to the volume of the system. The us of more sorbent material / litre of a gas to be pumped will enable lower pressure to be achieved. Multistage pumping, which is a much more effective method, uses one pump to remove the bulk of gas, which is valved off and then uses another pump to continue the process. The first stage can be either sorption or a mechanical pump. Oil contamination from a mechanical pump can be minimized by a trap. Advantage of mechanical pumping in the first stage is the ultimate partial pressures of neon and helium, which are not pumped by sorbents, can be greatly reduced. However in systems where the final vacuum is in the ultra high vacuum range, where oil contamination is not allowed, we should avoid use of mechanical pumps.

Both zeolites and activated charcoal are used as sorbents. Zeolites are more commonly used due to their short regeneration time, higher capacity and greater freedom from rusting.

Chapter 4

EXPERIMENTS WITH VACUUM

1. Dependence of boiling point on pressure

2. Sound propagation in vaccum

3. Forces created by vaccum

EXPERIMENTS CONDUCTED:

Aim:- using a simple vaccum experimental stand following experiments are to be done.
(i)- dependence of boiling point on pressure,
(ii)-sound propagation in vaccum,
(iii)-forces created by vaccum,

THEORY:

Dependence of Boiling Point on Pressure

Boiling point of water gas down with the ambient pressure.$1/40^{th}$ of atmosphere water boils at room temperature (30 C).To observe this a small beaker containing 50cc of water and thermometer is kept on a thermocol piece located inside the veccum belljar of the experimental pump stand. The pressure inside this belljar (as measured by the manometer attached)is made to go down with the help of rotary pump, in air ballast mode after some time we can start observing the fall of the temperature in the thermometer caused by the cooling due to evaporation of water. This confirms that the boiling point of water has come down to room temperature under vaccum conditions.

Sound Propagation in Vaccum

Keep an electric bell on a sound deadeing base (foam plastic) to exclude sound propagation via the base plate and the glass belzar. Excite the bell by passing current through its coil with the help of vaccum compatable electrical feed through attached to base plate. Initially, when the pressure inside the belljar is 760 torr, we can clearly hear the sound. When we repeat this experiment under vaccum conditions (10^{-1} torr), we will not be able to hear the sound of the bell. This observation clearly proves that sound can not travel through vaccum and need an atmosphere.

Force due to Vaccum

Guericke(1654) was the first to show the practically useful mechanical of effects associated with forces due to pressur difference between vaccum and atmosphere.
His famous experiment in Magdeburg demonstrated that the two gasketed copper hemispheres with sufficient vaccum in side couldn't be pulled apart with 2 x 8 horses until air

was readmitted into the ball. This force concept was later (1850) used in pneumatic –vaccum transport systems such as delivering of mail in paris.

We have a small size Magdeburg hemispheres which can be held together with the help of vaccum inside. The vaccum sealing between the two hemispheres in achieved by an 0-ring fitted in a suitable slot. It can be observed that the two hemispheres which are disconnected at atmospheric pressure can now be held tight together when evaculated with the help of a rotary pump for every sq.cm. area on the ball we now have a 1 kg force.

DETAILS OF EXPERIMENTAL SETUP:

Fig 4.1 apparatus constructed in NIT Rourkela for experiments with vacuum

Fig. 4.2 bell jar with bell and beaker with thermometer

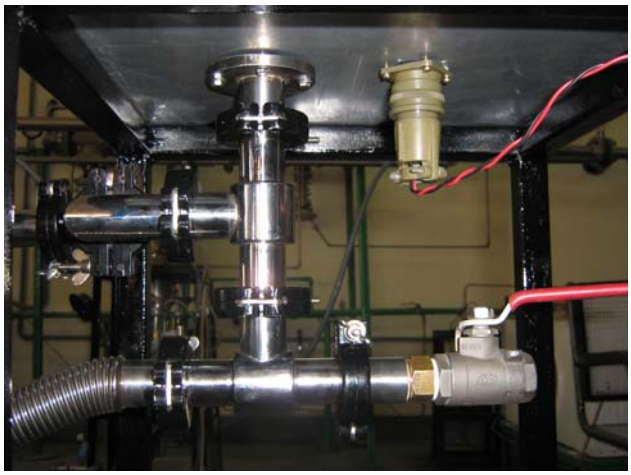


Fig. 4.3 ball valve, electrical connector for bell and flange with o-ring

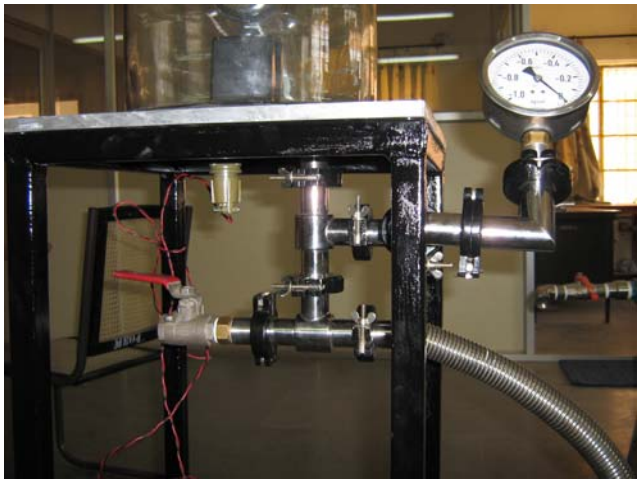


Fig. 4.4 connection to pump and pressure gauge

Chapter 5

PUMPING SPEED MEASUREMENT BY CONSTANT VOLUME METHOD

Aim: To measure the pumping speed of the pump by using constant volume method.

Theory: Pumping speed of a pump is given by :

$$Sp = (VdP/dt) / Pavg.$$

Where , Sp = pumping speed(lpm)

V = volume of vessel (l)

dP/dt = rate of change of pressure (bar/min.)

1. Connect the vessel to pump with a pipe.
2. Now switch on the pump and let the pressure drop in the vessel.
3. Take reacting at regular time interval .
4. Calculate dP/dt for consecutive readings.
5. Calculate pumping speed at an average pressure =$(P_1+P_2)/2$.
6. Draw pumping speed v/s pressure graph.

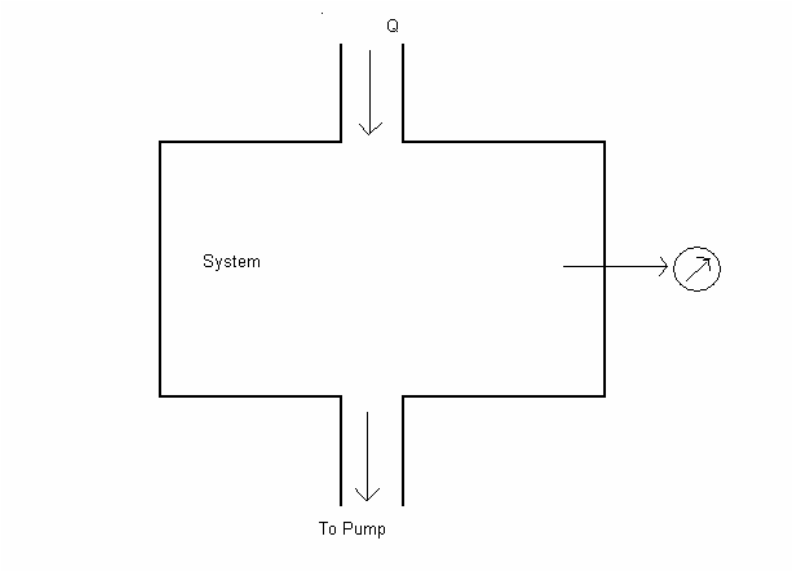


Fig. 5.1diagram for constant volume method

Tabulation:-

sl. no.	Pressure(P)	Temp. (t)	$\Delta P=P_1 - P_2$	$\Delta t = t_1 - t_2$	$P_{avg}=(P_1+P_2)/2$	$S_p=V(dp/dt)/ P_{avg}$

Table 5.1 table for calculating pumping speed

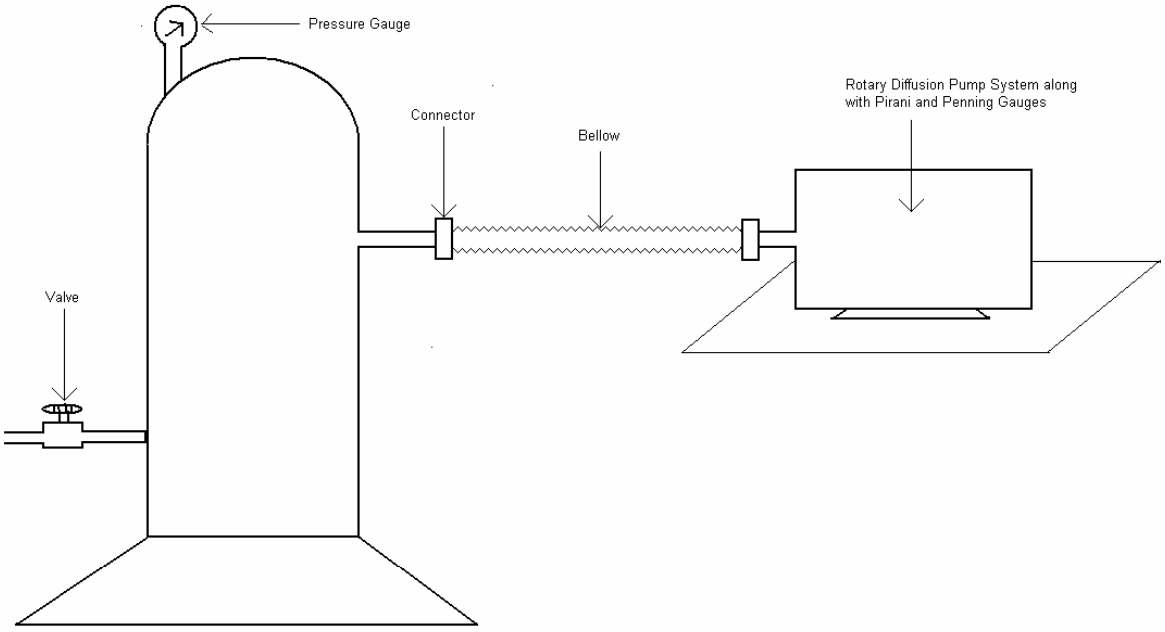


Fig 5.2 sketch indicating various components and setup for constant volume method for pumping speed measurement

Fig 5.3 apparatus set in laboratory of NIT Rourkela for pumping speed measurement by constant volume method

Chapter 6

PUMPING SPEED MEASURMENT BY CONSTANT PRESSURE METHOD

CONSTANT PRESSURE METHOD:

Pumping speed, $S_p=Q/P$

1. Adjust needle value for entering Q till the pressure gauge shows constant reading.
2. Measure $S_p=Q/P$.
3. Repeat this for various values of Q & P.
4. Plot S_p Vs P for various values obtained.

Fig 6.1 New Apparatus Set in the Laboratory Of IIT khargpur
For meauremnt of pumping speed by constant pressure method

Fig 6.2 from left Sourabh Raghuvanshi. Prof. V.V Rao(HOD, Cryogenics Centre), Devendra Nenava with the apparatus set in laboratory of IIT kharagpur

Experiment:

In constant pressure method vessel is connected to a pressure gauge and another part is connect to a needle valve which is further connected to a shut off valve and burette with the help of rubber tube and burette stand. Burette is dipped into a beaker full of rotary pump oil. Now arrangement is provided to connect vessel to a pump through a shut off valve. The fluid level in the flow meter reservoir should be high enough to cover the lower end of the burette, when the fluid is at maximum height in the tube during measurement.

1. First of all open the shut off valve v1 and connect pump to the vessel.
2. Let pressure falls to about 10^{-1} torr. Now open valve v2 and slowly slowly start opening needle valve (N).
3. Now pressure will start rising because of opening of needle valve.
4. Adjust needle valve such that pressure becomes constant in vessel.
   i.e. air taken by pump = air coming into the vessel by needle valve.
5. When pressure is constant for sufficient time (1 to 2 min) then close the valve (V2) in flash.
6. Now air in burette will start entering into the vessel because of pressure.
7. This will lead oil in the beaker to rise in the burette.
8. Calculate the volume of oil rising in fixed time.

9. By knowing this we will get volume of air that leaked into vessel during measured interval of time.
10. Thus, since the pressure and volume of the entering air are known, as well as the pressure in the enclosure, the rate at which the pump is removing air can be calculated by using the equation S=Q/P,

    where, Q= [atmospheric volume(Va) x atmospheric pressure (Pa)]/ [time in sec.(t) for Va to enter the vessel]

    P= pressure in vessel during the test.
11. Repeat this process at various pressure between 10^{-3} and 1 torr.
12. Plot these calculated speeds against pressure on graph paper .

Chapter 7

CONDUCTANCE MEASURMENT IN VACUUM PIPING NETWORK

CONDUCTANCE MEASURMENT IN VACUUM PIPING NETWORK

Aim: Construction of laboratory apparatus for measuring the conductance of different Pipes commonly used in vacuum work and to understand the effect of interconnecting piping on the overall pumping speed.

Principle and theory:

Through put (Q) & pressure drop (ΔP) are related by a term called Conductance "C" of the vacuum element (connecting tube),

$$C=Q/\Delta P$$

This equation can be considered as Ohm's law of vacuum technology.

Also,

For parallel conductance,

$$C_0= C_1+C_2+ C_3+\ldots\ldots\ldots\ldots\ldots$$

And for series conductance,

$$1/ C_0 =1/ C_1 + 1/ C_2+ 1/ C_3 \ldots\ldots\ldots\ldots\ldots$$

Where,

C_0 = overall conductance

C_1, C2, $C_3\ldots\ldots\ldots$ = individual conductance

(Reference: Vacuum Science and Technology By: V .V. Rao)

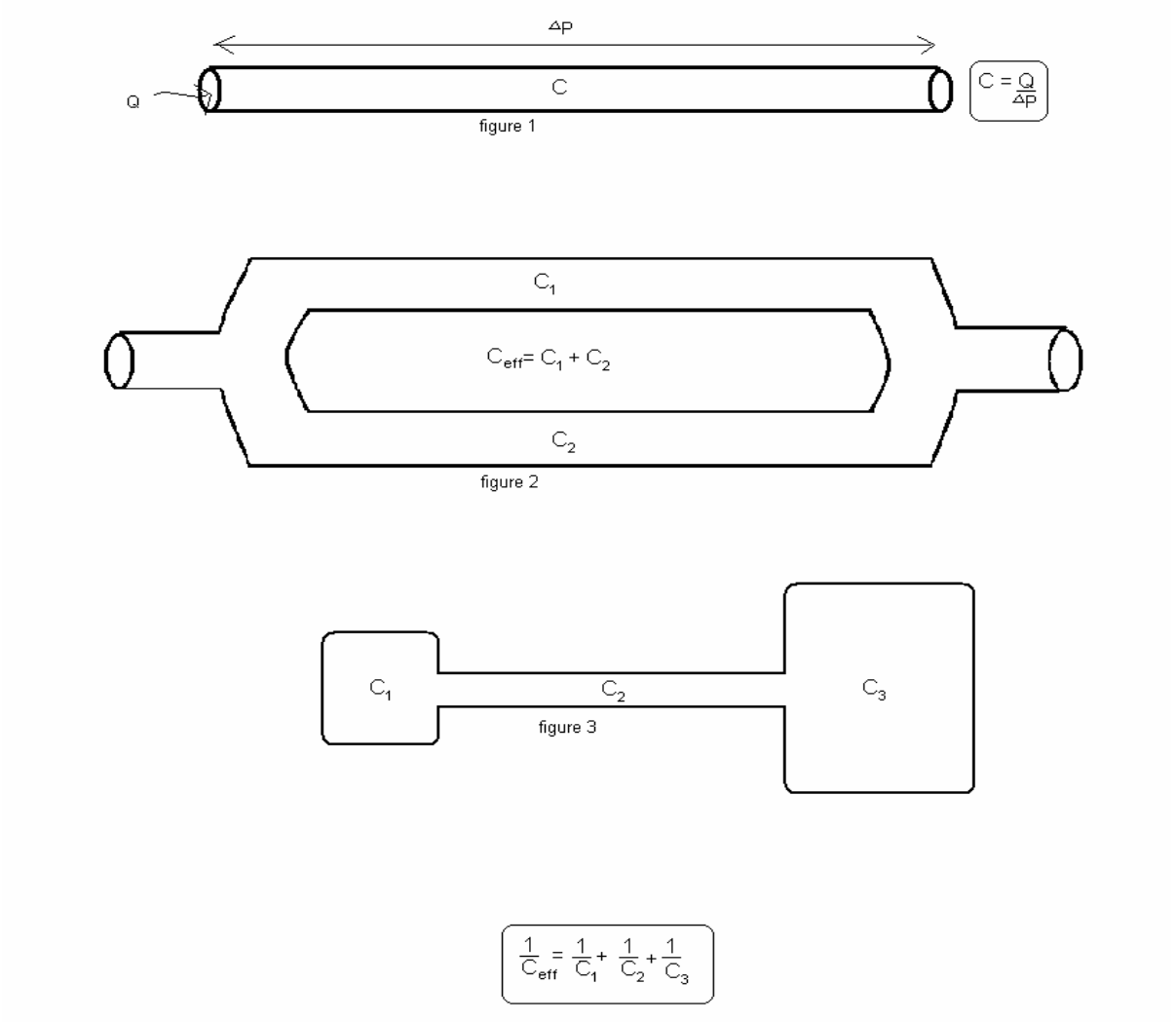


Fig 7.1 pressure conductance and throughput relation

Fig 7.2 conductances in parallel

Fig7.3 conductances in series

Effective pumping speed:

Pump speed,

$$S_p = Q / P_i \qquad \text{-------- } (_1)$$

Q=through put of pump

P_i=pressure of inlet of pump

System pumping speed,

$$Seff = Q/P \qquad \text{-------- (2)}$$

(Effective pumping speed)

P=pressure within the vacuum space

Overall conductance of piping system between vacuum space and vacuum pump is related to throughput by

$$C_0 = Q/(P - P_i)$$

$$\Rightarrow \quad (P/Q) - (P_i/Q) = 1/C_0$$

$$\Rightarrow \quad 1/S_{eff} = (1/S_p) + (1/C_0)$$

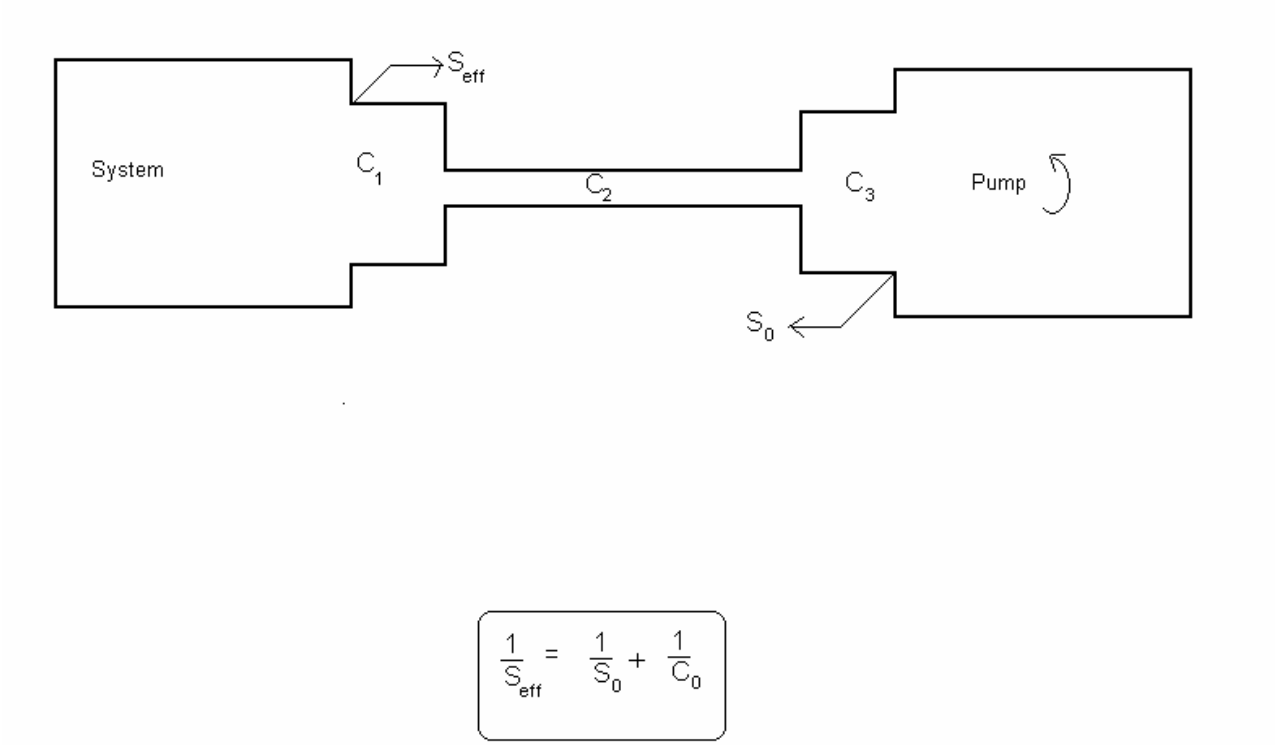


Fig.7.4 diagram showing relationship between effective pumping speed, actual pumping speed and overall conductance

So, when a pump with a maximum speed S_p is connected to a system, with the help of some piping system having overall conductance C_0, effective pumping speed (S_{eff}) of pump at the system side is reduced.

FREE MOLECULAR FLOW AND VISCOUS FLOW:

When molecular collisions dominate, it is viscous flow.

When rate of flow is determined by collision of molecules with the tube walls rather then molecule – molecule collision, it is free molecule flow.

If P is average pressure is (in microns of Hg) and D is lateral dimension of pipe (i.e. dimension in cm)

Then if

PD < 15 => free molecule flow

15<PD <500 => intermediate flow

PD>500 => viscous flow

DERIVATION OF CONDUCTANCE FOR FREE MOLECULE FLOW

(a) Aperture in a thin wall connecting two vessel which are large compared with the maximum aperture dimensions.

Hence, $Q=\sqrt{}(RT/2\pi m)(P_1-P_2)A$ ---------- (3)

R=Gas constant $=8.314\times10^7$erg/dg/mol

T=Temperature (K)

M= molecular weight

A=area of aperture (cm^2)

P_1=higher pressure on one side of aperture

P_2=pressure on other side

Putting values of R =8.314KJ/kg/K, M=29kg(for air) and T=20^0C =293 K

we get

$Q=11.6(P_1-P_2)A$ lit-torr/sec

$Q/\Delta P=C$

Reference: Principle of Vacuum Technology By-Pirani and Yarwood

So, conductance of air at 20^0C,

$C_{air}=11.6A$ lit/sec

$= 9.1\ D^2$ $(A=\pi/4\ D^2)$

Since, flow rate is directly proportional to average velocity of molecules (according to kinetic theory of gases),

So, conductance 'C' of any gas at any temperature is given by,

$C/C_{air} = (\sqrt{}T/m)/(\sqrt{}293/29)$

$C= C_{air}(T/293\times29/M)^{1/2}$

$C=11.6A\ (29/M \times T/293)^{1/2}$

$C=9.1D^2(29/M \times T/293)^{½}$ …… (4)

(b) Long tube of circular cross-section connecting to large vessel (impedance due to aperture is negligible)

Hence,

$Q=1/6(\sqrt{}2\pi RT/M)(D^3/L)(p_1-p_2)$ …….(5)

(D,C in cm)

For air, M=29 & T=293K

So,

$Q= (12.1\ D^3/L)(p_1-p_2)$ lit-torr/sec.

So, conductance of air at 20^0C for long tube,

$C_{air}= (12.1\ D^3/L)$ lit/sec.

For any gas,

$C= C_{air}(T/293\times29/M)^{1/2}$

$C= (12.1\ D^3/L)\ (T/293\times29/M)^{1/2}$ lit/sec. …… (6)

(c) Short tube of circular cross-section connecting to large vessel (impedance due to aperture is not negligible)

$(1/C) = (1/C_{apture}) + (1/C_{tube})$

$=1/ (\sqrt{RTA}/ 2\pi M) +1/ [(!/6)(\sqrt{2\pi RT/M})(D^3/L)]$ (from 5 & 6)

& $A=\pi/4\ D^2$

Let $r = C_{apture} / C_{tube} = [\{\sqrt{(RT/2\pi m)}\} (\pi D^2 /4)] /[1/6(\sqrt{2\pi RT/M})(D^3/L)]$

$= 3L/4D$

$C= \{C_{apture} \text{ x } C_{tube}\}/ \{C_{apture}+ C_{tube}\} = 1/6(\sqrt{2\pi RT/M})(D^3/L)\{1/ (4D/3L +1)\}$

For air at 20^0C, (M=29)

$C = (12.1\ D^3/L)\ \{1/ (L+4D/3)\}$ lit/sec

$= 3.638A\ (\sqrt{T/M})\ \{1/ (1+3L/4D)\}$ lit/sec. …… (7)

CORRECTION BY CLAUSING

Clausing showed that eq.(7) is not exact because the aperture at the end of circular tube can not be treated simply as a series conductors.

Conductance, $C =Q/p$

$= \ddot{u}AK/4$ (from kinetic theory)

$\ddot{u}$= avg. velocity of molecule

$= \{\sqrt{}\ (8RT/\pi m)\}$

Since $Q= pV$

(V= vol/sec)

$C= \ddot{u}AK/4$

$= \{\sqrt{}\ (8RT/\pi m)\}* AK/4$

Hence,

K=Clausing factor & is a fuction of L/r only for a cylindrical tube of length L & radius r.

It is the fraction of molecule which will pass right through the tube, i.e. they will not collide with the walls.

At T=293K & M=29, $C_{air} = 11.6AK$ lit/sec.

$=9.1KD^2$ lit/sec.

where K = 1/ {1+ (3L/4D)} (from eq^n 7 approximately)

C at any temp.

$$C = 9.1KD^2 (T/293\times29/M)^{1/2}$$

$$C= fD^2 (T/293\times29/M)^{1/2} \quad \text{……..(8)}$$

Value of f can be calculated using tables & graph.

For L/D=0, eq^n (8) gives conductance of aperture

For L>>0 eq^n (8) gives conductance of a long pipe.

For L/D>20, then it can be considered as a long pipe & aperture effect can be neglected.

For viscous flow

(PD>500)

$C = 3.3 \times 10^{-5}(D^4P/nL)$ lit/sec …….(9)

n =viscosity in poise

P=pressure in microns

D, L in cms

For mixed flow

(15<PD<500)

$C = 3.3 \times 10^{-5}(D^4P/nL) +10D^3/L$ ……..(10)

EXPERIMENT (measurement of Conductance)

1. Through calibrated leak value, introduce dry air at known mass flow rate (Q) measured in torr-lit/sec.
2. Pressure gradient (ΔP) across the tube is to be measured with calibrated gauges.
3. Then Q/ΔP gives the conductance (C) of the element at the avg. pressure $(p_1+p_2)/2$.
4. Steps 1-3 are to be repeated for various avg. pressures.
5. Conductance Vs Pressure is to be plotted for a particular tube.
6. Steps 1-5 are to be repeated for pipes of various diameters.
7. Then, at the same pressure, conductance of a pipe as function of diameter is to be plotted.

8. Effective conductance of parallel & series combination is to be measured.
9. Theoretical expression validity is to be checked for above results.

Experimental Measurement of Conductance:-

1. First of all vessel is directly connected to the pump by a short pipe having 1' or 1.5' diameter .
2. Pump is switched on and pipe is evacuated completely.
3. After this pipe and pump system is connected to the vessel by opening valve.
4. Now after regular interval of time pressure in the vessel is measured.
5. By calculating VdP/dT we can find out the throughput by taking two consecutive readings.
6. This will give us actual (s) pumping speed at average pressure $(P_1+P_2)/2$.
7. Now close the valve and connect pump to the vessel by another long pipe whose diameter should be less.
8. Again repeat the procedure and thus calculate the effective pumping speed (self) at average pressure $(P_1+P_2)/2$.
9. Now by applying formula:

$$1/self - 1/S = 1/C$$

This will give us the conductance of the pipe at various pressure.

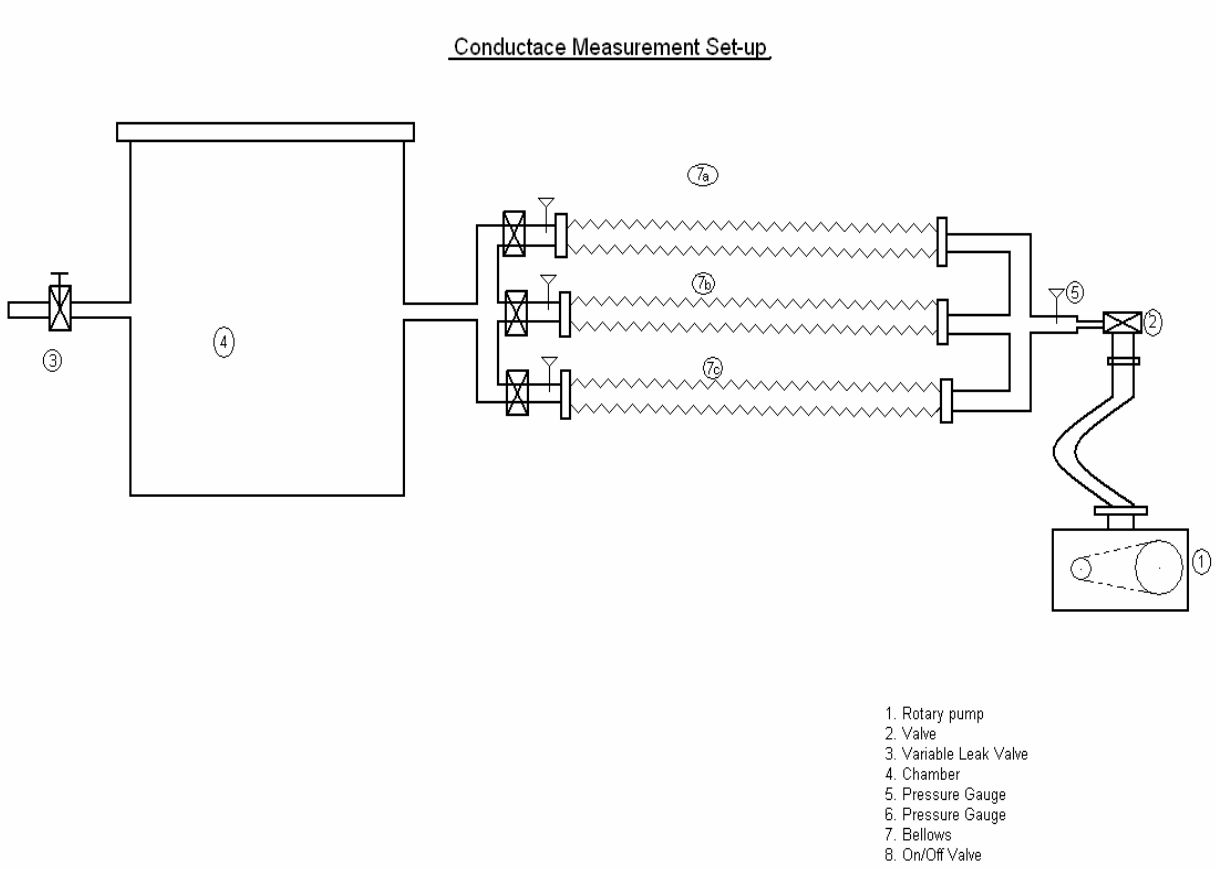


Fig 7.5 sketch showing various parts of the setup required for the measurement of conductance

Chapter 8

DESIGN OF VACUUM VESSEL TO BE PURCHASED

DESIGN OF VESSEL (for vacuum experiments)

(by using Roark's formulas)

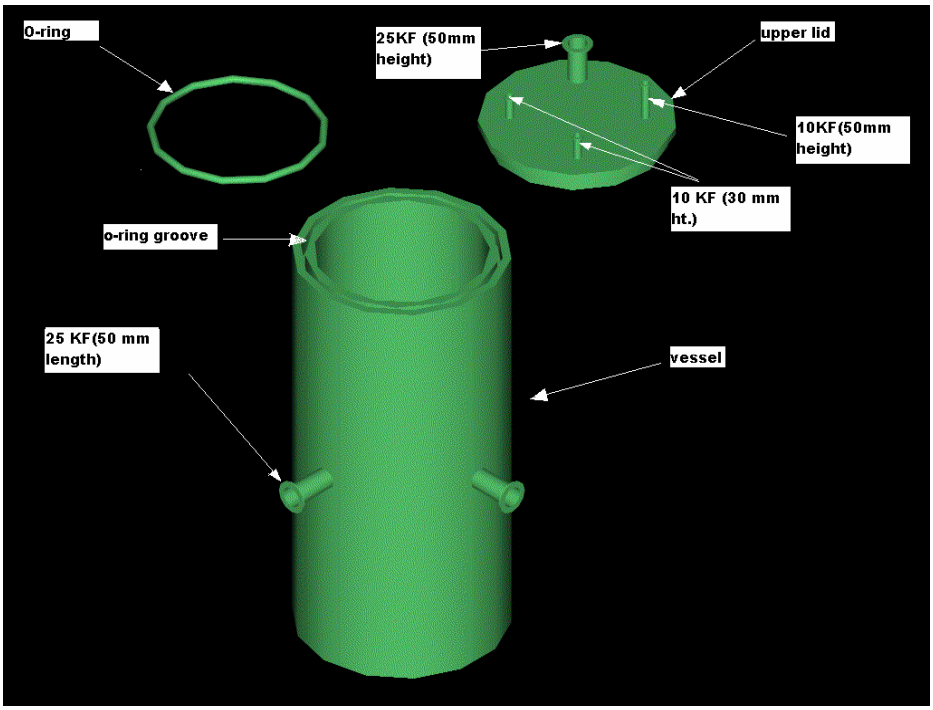


Fig 8.1 various components of the vessel

DESIGN OF THE UPPER LID OF THE CYLINDER

(by Roark's formulas for flat plates)

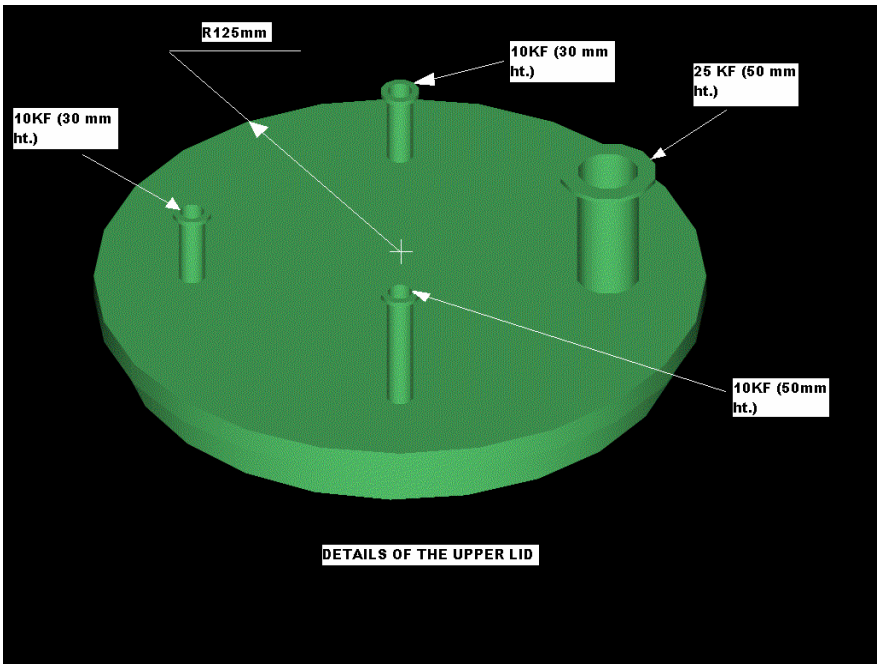


Fig 8.2 specifications of flanges on the upper lid

CONDITION 1 - flat plates supported at the edges &uniformly loaded over the entire surface.

Maximum stress ;σ max =-3W (3m+1)/8πt^2

Where; w=total applied load

m=reciprocal of poisson's ratio(1/μ)

t=thickness of the plate

$W=P*\pi r^2$

$P=1.01*10^5$ N/m^2

r=0.128 m

μ=0.3 ; so, m=1/(0.3)

t=?

σ max=$241*10^6$ N/m^2

σ max=$-3W(3m+1)/8\pi mt^2$

$241*10^6 =-3*1.013*10^5*\pi*(0.125)^2$ (3+0.3)/8*πmt^2

t=2.85 mm

by Roark's formula

y max.=$-3W(m-1)(5m-1)r^2/16*\pi*Em^2*t^3$

$E=207*10^9$ N/m^2

Where; r= radius of the plate

E=young's modulus of elasticity

t=thickness of the plate

y max. =$-3*1.013*10^5*\pi*(0.125)^2*(1-0.3)(5+0.3)*(0.125)^2/16*\pi*207*10^9*(2.85*10^{-3})^3$

=0.083mm

Now as y max.=0.083 mm<t/2

So, Roark's formula is valid in this case &design is safe

Considering factor of safety =3

t min =2.85*3

t min=8.55mm

we take t=10mm

DESIGN OF VESSEL

By applying Roark's formula for elastic stability of shells.

Conditions- Thin tube with closed ends under uniform pressure, lateral & longitudinal

Considering buckling to occur at pressure p'

$p'=E(t/r)\{1/n^2[1+(nl/r\pi)^2]^2 +n^2t^2/12r^2(1-\mu^2)[1+(\pi r/ml)^2]^2\}/\{1+((1/2*\pi r/nl)^2\}$

where,E=young's modulus of elasticity

t=thickness of the cylinder

n=number of lobes formed=1

l=length of the cylinder

μ=poisson's ratio

put p' =1 atmosphere=$1.01*10^5$ N/m^2

$1.01*10^5=207*10^9t\{\{/(1+\{0.5/3.14*0.125\}^2)^2+ t^2\{1+(0.125*3.14/0.5)^2\}^2/12*(0.125)^2(1-0.3^2)\}$ /0.125[1+1/2(3.14*0.125/1*0.5)2]

$8*10^{-8}=t[0.145+15.31t^2]$

$15.31\ t^3+0.145\ t - (8*10^{-3}) =0$

This give, $t= 5.5 *10^{-7}$ m

$t=5.5*10^{-4}$mm

CONDITION 2- Thin tube under uniform lateral external pressure

$P' = 0.807\ E\ t^2((t^2/(1-\mu^2)^3r^2)^{1/4})/lr$

$1.013*10^5 =0.807 *207*109 *t^2((t^2/(1-0.3^2)^3*0.125^2)^{1/4})/(0.5*0.125)$

$2.06*10^{-30} =t^8*t^2/(1-0.3^2)^3*0.125^2$

$t^{10}=2.429*10^{-32}$

$t=6.89 *10^{-4}$ m

t=0.689 mm

CONDITION 3- Th**in walled circular tube under uniform longitudinal compression**

$\sigma=1*E*t/((3)^{1/2}*(1-\mu^2)^{1/2}*r)$

$241*10^6=207*10^9*t/((3)^{1/2}(1-0.3^2)^{1/2}*0.125)$

$t=2.4*10^{-4}$m

t=0.24mm

taking above 3 conditions into account , we take t=3mm….

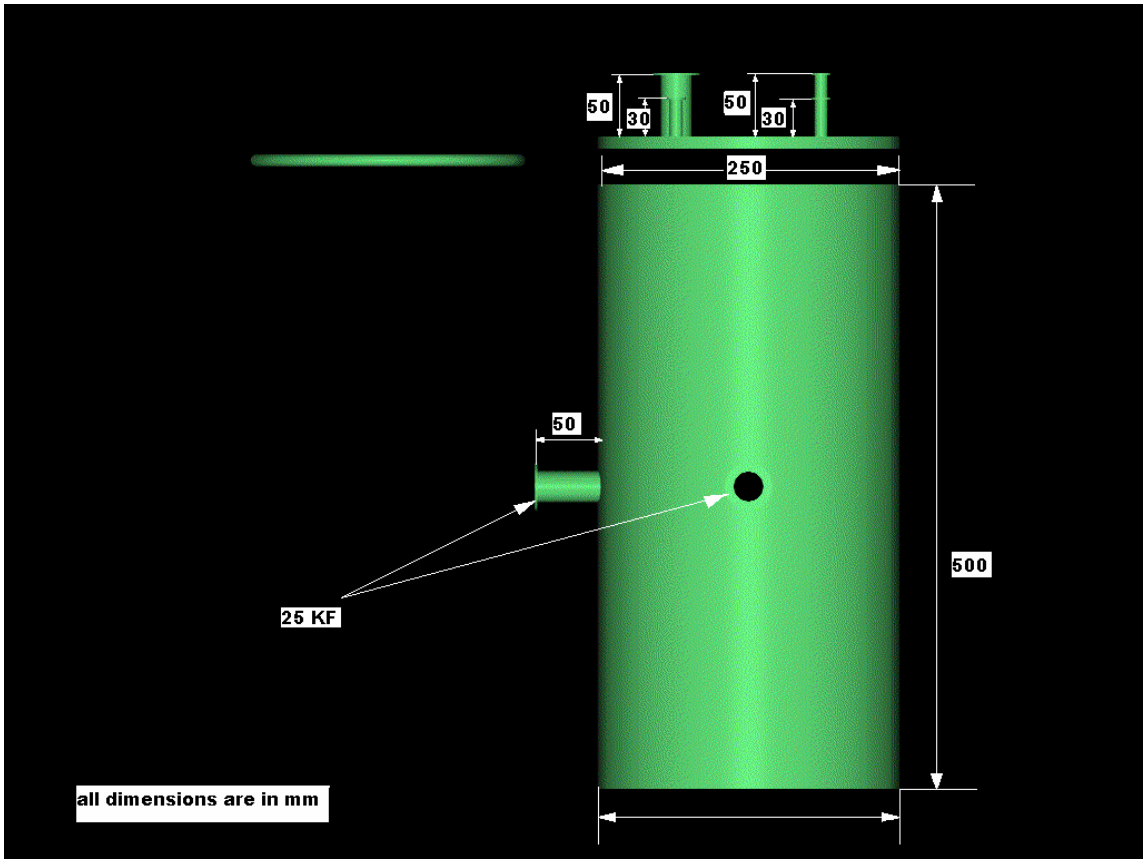


Fig 8.3 front view showing final dimensions of the vessel

Chapter 9

CRYOGENIC APPARTUS STUDIED IN IIT KHARAGPUR

LIQUID NITROGEN DEMONSTRATION SET UP

Fig.9.1 liquid nitrogen demonstration system in cryogenics laboratory. IIT Kharagpur

VARIOUS COMPONENTS STUDIED:

1)Super Insulated Vessel:

This vessel is used for the storage of liquid nitrogen in the apparatus from which it can be transferred to various transfer lines for various applications. It is cylindrical in shape with a conical neck.

Specification of the vessel:

Material : stainless steel 304

Cylindrical diameter : 35cm

Height of the cylinder : 60 cm

Capacity : 25L

Operating temperature : -196^{0}C

Various components attached to the vessel:

1) Transfer line at bottom:

This transfer line at the bottom is provided for taking out liquid nitrogen . since, liquid nitrogen in the upper part will be in vapour state , so liquid nitrogen is taken out from the bottom.

2) Pressure relief valve:

Insulated thickness part of the transfer lines is provided with a pressure relief and seal off valve. It is used for creating vacuum by connecting it to vacuum pump and then, sealing it off. Also, it acts as a pressure relief valve when a crack may occur and liquid nitrogen penetrates in the insulated region. It is provided with a protective cap at the top.

3) Liquid nitrogen filling system:

Fig. 9.2 filling system with level indicator

Fig 9.3 with sintered bronze filter

This consists of three passages which have a common super insulated covering just above the cylinder. They are:

a) Liquid Nitrogen filling line with sintered bronze filter:

Liquid nitrogen filling from the source comes through this filling line and enters the Dewar. It has got a sintered bronze filter at the delivering end. It causes slow filling of Dewar by reducing the pressure and hence the boil-off will be less.

b) Boil-off gas line:

There is a passage provided through the mouth of cylinder for the liquid nitrogen vapour which is continuously forming at the top surface to escape out.

c) Level indicator or sensor:

A level indicator may be of resistance or capacitance type. Here, resistance type is used. A number of wires pass through a Teflon tube through the passage provided, in the cylinder. Holes are provided in the Teflon tube along its length and towards the end so that liquid nitrogen can come in contact with the wires. Resistances of the wires vary in accordance with the level of liquid and hence it gives different readings at different levels. Provisions are provided to stop the passage of liquid nitrogen through this pipe.

This liquid nitrogen filling system is coupled to the mouth of the cylinder. The super insulated covering of these three passages also carries a pressure relief and seal off valve.

Middle cylinder portion is welded to upper conical part and the lower filleted potion. It is also welded at sides through plates to the supporting stands for providing support.

2)Smaller Dewar: (2 in numbers)

Specification

Super insulated metal Dewar 'Stella D150/300'

Operating temperature	: -196^{o}C
Material	: stainless steel
Outer diameter	: 20.5 cm
Inner diameter	: 15 cm
Thickness	: 2.75
Height	: 39 cm
Weight	: 6.5 kg
Pressure	: 0.1-1 bar
Temperature	: -196^{o}C to 20^{o}C

Fig. 9.4 storage dewar

They are of open system type with a Dewar cap which contains hard foam of diameter 14 cm and height 5 cm. they can be directly filled from source Dewar through transfer line governed with an extended stem type vacuum shut off valve at the end.

3)Super insulated transfer lines:

Specification:

Material: stainless steel

Outer pipe diameter : 52 mm

Inner pipe

Outer diameter : 16mm

Thickness : 1 mm

Space between inner pipe and outer pipe is super insulated. These transfer lines contain various valves, couplings etc. And are welded at each joint or bend.

4)Insulated transfer hose:

Fig. 9.5 transfer line

These are of flexible types to facilitate fillings of Dewars. They are used of connecting the end of super insulated pipe lines to the dewars and filling them up. They are made up of an inside material Teflon with an outer sleeve of stainless steel. They can be insulated or super insulated type. They may incorporate certain bellows at ends to increase flexibility. for the given apparatus.

Outer diameter of super insulated flexible pipe for connecting source vessel to rigid line is 35-36mm while that used for filling the smaller dewars has an outer diameter of 16-17 mm.

5) Safety valve:

Fig. 9.6 safety valve

Safety valves are used to relieve pressure when pressure goes beyond a certain limit. For the given apparatus set pressure is 8 bar for transfer live and 5 bar at inlet from source Dewar in flexible line.

6) Shut-off valve:

Fig 9.7 extended type stem valve

They are used for stopping the fluid flow through a certain path. They are of extended stem type. They may be vacuum or super-insulated type depending upon the application. For this apparatus, a vacuum type is used at end for filling small Dewar while an insulated one at the end coming from the source vessel.

7) super-insulated solenoid valve:

Solenoid valves are by default either closed type or open type. They can be operated by switching on the power whenever required.

8) Pressure-relief and Seal off valve:

Fig. 9.8 pressure relief valve

Insulated thickness part of the transfer lines is provided with a pressure relief and seal off valve. It is used for creating vacuum by connecting it to vacuum pump and then, sealing it off. Also, it acts as a pressure relief valve when a crack may occur and liquid nitrogen penetrates in the insulated region. It is provided with a protective cap at the top.

9) Super-insulated valve:

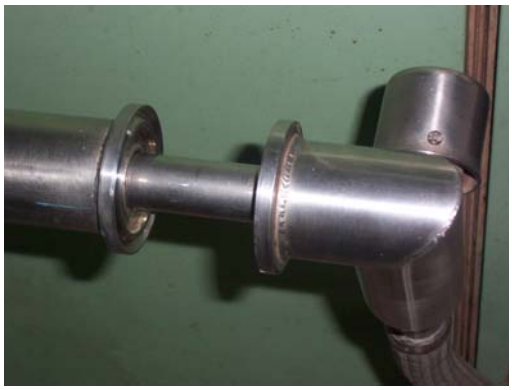


Fig. 9.9 super insulated coupling

Transfer lines are coupled at various joints through super-insulated couplings. One part enters the mating part to a sufficient length to reduce heat leakage and then they are screwed up.

10) Ball valves:

They are used for blocking or allowing a fluid to pass through a line. They can be operated in on position or off position only, that is, an adjustment cannot be made.

11) Support stand:

Support stand is made of aluminium with a cross section of 6cm*6cm throughout. A 1cm wide and 1.4cm deep cut has been provided on all its surfaces and throughout its length for enabling of screwing of various parts. This space is covered by a plastic strip for most of its length. This stand consists of various individual square rods bolted together. Wheels are provided at the bottom of the stand to facilitate mobility.

13) Clamps:

Fig. 9.10 elbow type clamp

Various clamps, bolts etc are provided for clamping of square rods within the stand and for clamping of apparatus to the stand for providing it a fixed support.

14) power board:

It is required for meeting the requirements of level indicator adura-β and solenoidal valves.

References:

1) Flynn Thomas M. - Cryogenic Engineering
2) Barrons Randal F.- Cryogenic Heat transfer
3) V.V. Rao - Vacuum Science and Technology
4) Pirani and Yarwood – Principles of vacuum engineering
5) Bruner W.F. and Patton H.G.- Experiments by American Vacuum Science Society

DEVELOPMENT OF EDUCATIONAL MODELS FOR TRAINING ON CRYOGENICS AND VACUUM TECHNOLOGY

Devendra Nenava and Sourabh Singh Raghuvanshi

Supervisor: Prof. S.K. Sarangi

Technical Assistance: Mr. V. Mukherjee

Abstract:

This project deals with study, design and construction of laboratory apparatus in Cryogenics Engineering and Vacuum Technology field. Project's aim is to develop such laboratory apparatus and model which can serve as the laboratory experiments for both undergraduate and post graduate students. This project work is broadly classified into two sub projects:--

1. Design and Construction of Cryogenic Apparatus.
2. Design and Construction of various apparatus related to Vacuum Technology.

Introduction:

In the cryogenic field, an apparatus has been designed which will use liquid nitrogen as the working fluid and will demonstrate various accessories of a basic cryogenic setup such as storage Dewars, insulated pipelines, valves etc. Also leak measurement will be done with the help of two temperature measuring devices across a test pipeline.

For Vacuum Technology lab, construction of various apparatus for experiments related to boiling of water at room temperature and at reduced pressure,sound propagation in vacuum, pumping speed measurement by constant volume and constant pressure methods, conductance of different pipes, other such experiments like are to be carried out.

Experimental:

Design and construction of various apparatus and experiments conducted

1) Pumping speed measurement by constant volume method.
2) Pumping speed measurement by constant pressure method.
3) Boiling of water at room temperature & reduction in the intensity of sound with variation in vacuum level.
4) Conductance measurement in a vacuum piping (parallel) set-up.
5) Design of new vacuum vessels to be purchased.

6) Design of cryogenic apparatus for measurement of heat leak across a variable vacuum test pipeline & demonstration of various cryogenic accessories.

Results:

1)boiling of water at room temperature and at reduced pressure was carried out. It was observed that water boiled at $1/40^{th}$ of atm. Pressure at room temperature.

2)It was observed that intensity of sound decreases with increase in vacuum level.

3)pumping speed characteristics and pressure vs time graph for a rotary pump by constant volume method are obtained.

4)Design and bill of materials is completed for cryogenic apparatus, vacuum vessel and other vacuum experiments.

References:

1) Flynn Thomas M. - Cryogenic Engineering

2) Barrons Randal F.- Cryogenic Heat transfer

3) V.V. Rao - Vacuum Science and Technology

4) Pirani and Yarwood – Principles of vacuum engineering

5) Bruner W.F. and Patton H.G.- Experiments by American Vacuum Science Society